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DOCTOR OF PHILOSOPHY

Modelling fourth-party logistics transaction centre for evaluation and integration of trading partners using data envelopment analysis

Kumar, Sharath

Award date:
2015

Awarding institution:
Coventry University
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MODELLING FOURTH-PARTY LOGISTICS TRANSACTION CENTRE FOR EVALUATION AND INTEGRATION OF TRADING PARTNERS USING DATA ENVELOPMENT ANALYSIS

By

SHARATH KUMAR K.M.

JUNE - 2015

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SHARATH KUMAR K.M.

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A thesis submitted in partial fulfilment of the University's requirements for the Degree of Doctor of Philosophy

Coventry University in Collaboration with M.S. Ramaiah School of Advanced Studies

CERTIFICATE

This is to certify that the Doctoral Dissertation titled "Modelling Fourth-Party Logistics Transaction Centre for Evaluation and Integration of Trading Partners using Data Envelopment Analysis" is a bonafide record of the work carried out by Mr. K.M. Sharath Kumar in partial fulfillment of requirements for the award of Doctor of Philosophy Degree of Coventry University

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ACKNOWLEDGEMENTS

During the course of pursuing my Ph.D., I have learnt a lot as a research scholar and would like to thank many people from the bottom of my heart. In particular, I had the experience of learning with renowned Professors from M.S. Ramaiah School of Advanced Studies (MSRSAS) and Coventry University (CU), U.K. along with working on research topics with Industry partners. Indeed, I would like to express my sincere and heartfelt gratitude for their help, advice, suggestions and their continuous support during various stages of this research study.

Above all, I would like to thank my Director of Studies **Prof. H.K. Narahari** for being an endless source of encouragement and guiding light during the course of this project. Moreover, his timely advice and directions has made this thesis take necessary shape to satisfy academic standards. In parallel, I am also grateful to **Prof. Nicholas Wright** for accepting to be my CU supervisor. His continuous support and guidance assisted me greatly in completing this dissertation. I gratefully acknowledge the generous encouragement rendered by **Prof. S.R. Shankapal**, President, MSRSAS for his valuable suggestions, support and guidance. Besides, **Prof. S.R. Shankapal**'s advice has been a never ending inspiration throughout my research study. His priceless and consistent feedback helped my career leap to the next stage academically and personally.

With a deep sense of gratitude, I appreciate **Prof. Peter White** for being my Progress Review Panel (PRP) Chair and **Prof. Vinod K. Banthia** for being PRP-subject expert. The collective feedback and guidance have significantly helped my research from academic perspective. I also thank them for their patience listening and sharing their research experiences during review meetings to improve the standards of my research study.

It is also a great pleasure to express my thanks to **Prof. M.D. Deshpande**, Coordinator-Ph.D. Programme and **Prof. Govind R. Kadambi**, Dean-Academics, MSRSAS for providing necessary and sufficient resources, facilities and instigation to carry out this research. The modules handled by them during pre-Ph.D. have imbibed research culture and zeal in me to pursue research. Further, I would express my sincere thanks to my Ph.D. Examiners

Prof. Andrew Lyons, Prof. Aristides Matapoulos and Prof. Hing Kai Chan for their unflagging support and valuable feebacks to enhance the standards of my thesis.

I should also thank **Prof. K. Gnanamurthy** for being my mentor and constant source of inspiration to pursue research. I would like to thank **Mr. M.A. Alisha**, Vice President-Materials, VST Tillers Tractors Ltd. (VTTL) for spontaneously agreeing to provide industry support for my research. By virtue of his support, the proposed research has been validated through a case study approach. Therefore, I am eternally indebted to VTTL group for their great support to the academic fraternity. I would also like to thank **Mr. G. Suryanarayana, Mr. N. Manjunatha, Mr. Hari Krishna and Mr. Kodandaram** of VTTL for their continuous support in the form of providing relevant data to validate the proposed research.

I am also grateful to staff at the Academic Records Office for providing templates and extending their support during the course of my project work. I would like to express my gratitude to MSRSAS for allowing access to its library having a huge array of books, technical literature etc. and providing positive academic work environment during the research activity.

I wish to express warm and sincere thanks to my Parents **(Mr. K.N. Mohan Kumar and Mrs. C. Shakunthala)** for providing access to good education and endowing me with all the required conveniences. Without them this thesis would not have been a reality. Finally, I would like to extend sincere and heartfelt thanks to my wife **Dr. Archana** to walk through this journey with me. By virtue of her support and encouragement, I have been able to complete all the required course frameworks of this research study successfully.

I would also take this opportunity to express my sincere gratitude to those people who have extended their support directly or indirectly for executing the project. Last, but not the least, the blessings of Almighty has helped me to face difficult situations and challenges for completing this thesis.

K.M. Sharath Kumar
Bangalore, India
June 2015

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ABBREVIATIONS

3PL	Third-Party Logistics
4PL	Fourth-Party Logistics
ACO	Ant Colony Optimisation
ADF	Augmented Dicky-Fuller
AE	Allocative Efficiency
AHP	Analytical Hierarchy Process
ANP	Analytical Network Process
AVL	Approved Vendor List
BCC	Banker, Charnes and Cooper
BI	Business Intelligence
BSC	Balanced Score Card
CCR	Charnes Cooper and Rhodes
CI	Confidence Interval
c-RTS	constant Returns to Scale
CSCMP	Council for SCM Professionals
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
ERP	Enterprise Resource Planning
EVA	Economic Value Added
GDP	Gross Domestic Product
GIR	Goods Inward Receipt
ISM	Interpretive Structural Modelling
IT	Information Technology
LPP	Linear Programming Problem
LSPs	Logistics Service Providers
MCDM	Multi Criteria Decision Making
MEF	Model Efficiency Statistic
MSEP	Mean Square Error of Prediction
NN	Neural Networks

OE	Overall Efficiency
OEM	Original Equipment Manufacturer
OR	Operations Research
PLS	Partial Least Square
PTE	Pure Technical Efficiency
QMS	Quality Management System
R&D	Research and Development
RFI	Request For Information
RPI	Risk Probability Index
RQ	Research Question
SC	Supply Chain
SCI	Supply Chain Integration
SCM	Supply Chain Management
SCP	Supply Chain Procurement
SCR	Supply Chain Risk
SE	Scale Efficiency
TCE	Transaction Cost Economics
TDP	Total Delivery Performance
TE	Technical Efficiency
TQP	Total Quality Performance
TVR	Total Vendor Rating
USD	US Dollar
VAR	Vector Auto Regression
v-RTS	variable Returns to Scale
VQR	Vendor Quality Rating
VTTL	VST Tillers Tractors Ltd.

ABSTRACT

This thesis presents the modelling of an effective Fourth-Party Logistics (4PL) transaction centre which can evaluate trading partners and comprehensively integrate the improved competencies of trading partners for sustaining the post-merger effects. The proposed 4PL transaction centre is based on the *best of breed* concept to serve as a single point integrator. To create a *best of breed* 4PL set up, an exclusive performance measurement framework is proposed in a balanced approach by considering decision parameters from both the trading partners and the buying organisation perspectives. The novelty of the proposed 4PL performance measurement framework lies in its capability to integrate analytics with mathematical modelling resulting in a multi-stage framework which can be generalised to any industry. This thesis proposes the modelling of 4PL transaction centre through a computationally efficient Data Envelopment Analysis (DEA) approach considering time dynamics as an influential factor instead of conventional static evaluation. The versatile features of dynamic DEA approach are realised through the variable lag effects (positive, neutral or negative) on subsequent chain partners to emulate actual scenario by eliminating bias in the evaluation process.

Based on the derived outputs from the developed framework, this thesis enables to deal with a range of cross-segment mergers by extending the conventional Bogetoft and Wang's production economics integration model which is otherwise limited to mergers of similar-segment only. This thesis proposes a novel two-tier cross-segment integration framework for the 4PL transaction centre prioritising performance orientation in the first tier and cost orientation in the second tier to quantify the merger gain. The integration framework developed in this thesis facilitates the coordinator of transaction centre to manage and control 4PL activities. In summary, this thesis demonstrates an objective approach to quantify the 4PL value addition in a unified approach (evaluation and integration) with improved consistency and adequacy. The advantageous and desirable features attained by modelling the 4PL transaction centre are addressed specifically from operational perspective instead of available financial measures. This thesis also presents extensions to the proposed transaction centre to deal with multi-criteria decisions objectively along with risk considerations. The expected value additions from the proposed 4PL transaction centre are substantiated through a case study utilising real data of suppliers and logistics service providers from a tiller and tractor manufacturing company.

CHAPTER 1: INTRODUCTION

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1.1 Introduction and Motivation

In today's competitive environment, focus on core and non-core competencies is becoming order of the day for organisations seeking sustainable growth (Win, 2008). Visser (2007), Singh (2011) and Loureiro *et al.* (2015) have pointed out that the competition no longer takes place between companies but this happens between Supply Chains (SCs). In parallel, shorter product life cycle and high expectations from customers have made the SC coordinators to look at building relationships with the network members (Cruijssen *et al.*, 2007). This includes coordination and collaboration with the members of upstream and downstream SC network (Ballou, 2007). The network members of the SC can also be called as trading partners who can be referred to suppliers, intermediaries, third-party service providers, Logistics Service Providers (LSPs) and customers. Moreover, selection of trading partners involves Multi Criteria Decision Making (MCDM) techniques (Ho *et al.*, 2010). Due to high uncertainty and dynamic environment, companies are seeking to upgrade their business models continuously to handle pressure in competition (Tejpal *et al.*, 2013). Besides, globalisation and adaptation to Information Technology (IT) have changed the business rules in the contemporary organisations (Bulak and Turkyilmaz, 2014). This has led to the emergence of logistics and Supply Chain Management (SCM) concepts in non-core category (Shafiee *et al.*, 2014).

According to council of logistics management, "*logistics is the process of planning, implementing and controlling the efficient, cost effective flow and storage of raw materials, in-process inventory, finished goods and related information flow from point-of-origin to point-of-consumption for the purpose of conforming to customer requirements"* (Cooper *et al.*, 1997). Logistics is considered as an important part of any economy (Fong, 2005). Specifically, India is considered as the land of opportunities for LSPs and one of the global hubs for manufacturing and sourcing components due to its emerging economy (Lieb, 2008). However, the logistics cost in India contribute to around 13% of Gross Domestic Product (GDP) which is high compared to USA (9%) and Europe (7%) (Lieb, 2008; Soni and Kodali, 2011). This variation can possibly be attributed to regulatory issues, poor logistics infrastructure, complex tax laws and lack of standardised technological aids (Lieb, 2008). Besides, training and retaining well-equipped logistics manager is going to be a big challenge in India (Lieb, 2008). In reality, logistics is perceived as cost centric instead of revenue generating model for attaining customer satisfaction (Mody, 2009; Maha, 2009). Further, export of auto components alone is estimated to touch US Dollar (USD) 25 billion by 2016 (Madhavan, 2010). In the above context, globalisation in the current business environment has made SCM an interesting research topic (Loh and Thai, 2015; Cheng *et al.*, 2015).

Levi *et al.* (2003) reported SCM *"as a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system wide costs while satisfying service level requirements"*. Sahay *et al.* (2003) advocated the idea of creating agile SCs as the next logical step for value addition under MCDM environment. The value addition by the SC can be achieved through integration of trading partners and effective operations management (Cooper *et al.*, 1997; Bagchi and Larsen, 2002; Levi *et al.*, 2003). Hence, organisations are looking for standardisation of the integration process to achieve economies of scale and portray transparency across the SC network (Holweg *et al.*, 2005). Thus, SCM deals with effective integration of business functions such that all the processes are aligned to achieve the common goal. Council of SCM Professionals (CSCMP) – 2007 define SCM "*as an integrating function with primary responsibility for linking major business functions and processes within and across companies in to a cohesive and high performing business model*" (Mortensen and Lemoine, 2008). Groznik and Maslaric (2012) emphasized that SC network should be flexible, cost effective and information driven to achieve the common goal. The scope of this research is confined to operations perspective which is deemed as the second important business issue to satisfy the customers after strategic management (Kumar, 2008; Bennett and Klug, 2012). In particular, operations perspective includes the effective management of materials and their movement across the distribution network (Chopra and Meindl, 2007). Conversely, the selection of an appropriate coordination strategy is considered as a huge challenge for SC coordinators (Naesens *et al.*, 2007; Muller and

Aust, 2011). Chicksand *et al.* (2012) have reviewed 1113 research articles over 13 years in the field of purchasing and SCM to analyse the scientific coherence of terminology. The authors found lack of coherence in SC theories and frameworks creating confusion in the terminology.

In general, SCM strategy implementation requires trust among the different categories of trading partners (internal and external) in order to strengthen their relationship for supporting integration process (Green, Jr. *et al.*, 2008). Basically, strategy looks for achieving sustainable performance in the long-term (Kluyver and Pearce, 2006) in alignment with the client organisation requirements. According to CSCMP-2007, integration is defined as "*linking major business function and business processes* [....]" (Mortensen and Lemoine, 2008). Therefore, SC integration, which combines two or more independent entities, is deemed as a core activity for the success of a distribution network. Green, Jr. *et al.* (2008) indicated that logistics performance is affected by SCM strategy which in turn affects the firm's performance. In summary, SC coordination is an operation plan for organising the integration of network members to collaboratively work effectively and efficiently. This comprises of information interfacing and integration of operations in order to deliver the product optimally (Kwon and Suh, 2005; Visser, 2007) leading to a responsive SC. It may be noted that, SC terms like integration, partnership, cooperation and coordination are used synonomously in a similar context (Leeuw and Fransoo, 2009). In principle, a deeper integration between the different categories of trading partners leads to a reduction in operations cost and increase in stakeholder value. Nonetheless, the mild interactions lead to coordination and in-depth interactions facilitate the collaboration between network members. Thus, collaborative relationship is deemed as a highest order of integration wherein the trading partners are willing to share risks for long-term relationship (Thakkar *et al.*, 2005). Five key pillars of SCM strategy that forms the foundation of "***The New Supply Chain Agenda***" (Stank *et al.*, 2011) are reported as follows:

1. Talent
2. Technology
3. Internal Collaboration
4. External Collaboration
5. Managing SC change

This thesis focuses on external collaboration which involves the client organisation and its trading partners working together. The long-term relationship leads to positive behaviour between the network members leading to improved satisfaction with fewer chances of conflict. In addition, SCM strategy has to be inter-linked with the competitive strategy of the buying organisation to leverage growth and profits (Singh, 2011). In summary, SCM strategy consists of three key elements in the form of physical flow, information flow and relationship between trading partners (Tejpal *et. al.*, 2013). However, relationship management is considered as a key issue which can be managed only through trust (Chicksand *et al.*, 2012). In this case, the network members believe in each other's capabilities and competencies. Recently, there is a theoretical development of SC towards integrated and partnership oriented approach to gain competitiveness (Ogulin *et al.*, 2012; Evangelista *et al.*, 2013; Kiessling *et al.*, 2014). Hence, SCM is deemed to be the most crucial part of business in order to achieve the competitive advantage (Prajogo and Sohal, 2013; Kiessling *et al.*, 2014).

Naslund and Hulthen (2012) defined Supply Chain Integration (SCI) as "*coordination and management of the upstream and downstream product, service, financial and information flows of the core business processes between a focal company and its key suppliers and its key customers*". But, integration practices are found to be scarce in SCM due to the limited comprehension on benefits of collaboration and compatibility issues with IT (Bagchi and Larsen, 2002; Holweg *et al.*, 2005). Following the wide acceptance of SCM principles, an organisation's competitiveness is dependent on upstream and downstream chain partners' performance signifying the need for collaborative approach (Cheng *et al.*, 2008). Thus, the main objective of SC relates to adding maximum value at every intermediary stage in the network creating a *win-win* situation (Win, 2008). Currently, organisations view the entire globe as one market and foster trust with their trading partners through advancement in IT, reducing inventory and minimising the Bull-Whip effect (Evangelista *et al.*, 2013). Hence, there is a need to develop new advanced frameworks and mathematical models in the SCM domain to support integration process (Loureiro *et al.*, 2015). This process involves coordination of activities between *like-minded* trading partners through resource, technology and information sharing (Tan *et al.*, 2014; Loureiro *et al.*, 2015). This has led to the concept of Third-Party Logistics (3PL) which provides only a part of SC solutions (Lieb, 2008). In this thesis, *like-minded* trading partners comprise of network members with the same strategic intent working for a common goal. Prockl *et al.* (2012) defined 3PL as a contract logistics provider. In fact, the adaptation of 3PLs by the client organisation is deemed common in the current business scenario due to ever-increasing demand for outsourcing logistics activities in manufacturing and retail industry (Prockl *et al.* 2012; Tan *et al.*, 2014). Terms such as "logistics outsourcing", "contract logistics", "contract distribution" are viewed as synonyms for 3PLs (Prockl *et al.* 2012).

From the Asia-Pacific CEO's survey, Lieb (2008) noted that pressure on cost minimisation and increased expectations from the client organisations have put pressure on 3PLs. Most 3PLs provide the transportation and warehousing services but lack integration capabilities of cross-segment trading partners (Lieb, 2008; Tan *et al.*, 2014). In this scenario, the cross-segment trading partners comprise of different categories of network members working for a common goal (Anderssen *et al.*, 2010). For instance, the various categories of suppliers and LSPs may combine their operational capabilities in the form of a merger to provide optimal solutions. Since 3PL providers cannot offer global distribution, the client organisations look for a single point integrator to cope up with the challenges in business (Kumar, 2008). This has led to the emergence of Fourth-Party Logistics (4PL) which can manage the entire SC based on buying organisation's requirement. In addition, the capability to integrate various trading partners with single SCM focus is the main advantage of utilising 4PL (Win, 2008).

According to Business Line newspaper, developed countries are looking beyond 3PLs in the form of 4PLs. Globally about 75% of Fortune 100 companies and 45% of Fortune 500 companies use 4PLs. In India, companies like Dell, Nike, IBM and Philips have already outsourced their SC activities to 4PLs (Simhan, 2003). In addition, increased dependency on IT and complex SCs due to globalisation have led to the development of 4PL service providers (Bourlakis and Bourlakis, 2005). Langley *et al.*'s (2005) survey have minimised the ambiguity in understanding the terms 3PL and 4PL. For that reason, a two-tier relationship structure is represented in fig. 1.1 to avoid confusion in the terminology. The two-tiered relationship structure is classified into strategic and tactical regions.

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Figure 1. 1 Relationship structure of 4PL framework

Source: Langley et al. (2005)

In general, tactical situation deals with the mid-term activities and strategic condition covenant with long-term activities (Kluyver and Pearce, 2006). As 3PL service providers offer traditional logistics services, it comes under tactical region. The relationship attribute is entirely transaction oriented and contractual at this stage. The next level of relationship structure deals with cooperation and enabling trust in the form of SCM. In particular, the identification of *like-minded* trading partners for strategic partnerships along with risk sharing capabilities is known as 4PL or lead logistics providers (Langley *et al.,* 2005). Also, there is a trend where the 4PL service providers control different category of third parties (Visser, 2007). This requires understanding the client organisation requirements and capability to redesign the SC network focusing on long-term achievement. Thus, a 4PL service provider is considered as a strategic partner who can offer research based broad SC expertise with an in-depth industry knowledge. By virtue of this, the interaction increases between different categories of network members leveraging innovation (Visser, 2007; Mukhopadhyay and Setaputra, 2006). Besides, worldwide trend of globalisation have led many buying organisations to critically look at value adding capabilities of a 4PL service provider (Visser, 2007; Win, 2008). Visser (2007) reported that 3PLs and 4PLs can be differentiated based on their functions not firms. In addition, 4PL leverages flexibility to the companies for managing uncertainties and builds closer relationship between the trading partners by supporting cost cutting initiatives along with service enhancements (Win, 2008). Alternatively, the results of Lieb's (2008) study showed that asset based 3PLs are best suited to become 4PL service providers. The advantages for network members participating in integration include reduced uncertainty, dependence management, competing in unexplored markets with risk insulations (Thakkar *et al.*, 2005). The study by Win (2008) assumes that 4PL service provider possesses requisite skill sets to add value as compared to in-house operations. Above all, it is necessary to understand the roles of 4PL and their key competencies. Unlike 3PLs, 4PLs take over the complete control of the SC by managing exclusive buying organisation accounts as a non-asset based integrator (Chen and Su, 2009; Richey *et al.*, 2009). Thus, 4PL is regarded as a single point integrator to provide comprehensive SC solutions by combining the competencies of *best of breed* trading partners (Fulconis *et al.*, 2007; Richey *et al.*, 2009). The *best of breed* setup possesses different category of trading partners who are treated as benchmark members in their respective field of expertise. Moreover, research directions are emphasising on the next level trend of 3PLs in the form of 4PL (Prockl *et al.*, 2012). For instance, 3PL service provider delivers the books but 4PL service provider prints, delivers and bills the customer (Kutlu, 2007).

Due to scarce literature in 4PL domain, an attempt is made to compare and contrast different definitions along with a critique on the recent developments. Bauknight and Bade (1998) define 4PL as "*SC integrator which combines capabilities, resources and technology within its organisation as well as external organisations to provide effective SC solutions*". In general, 4PL service provider coordinates integration of cross-segment trading partner rather than participating in actual operations (van Hoek and Chong, 2001). According to Visser (2007), "*4PLs assemble and manage resources, capabilities and technology to deliver comprehensive solutions with analytical capability*". This comprises of reinvention, transformation and execution of coordinating chain partners. Hence, performance and success of this setup are measured as a function of value creation to the buying organisation (Visser, 2007; Win, 2008). Win (2008) reported 4PL concept as "*independent, singularly accountable, non asset based integrator of a clients supply and demand chains*". The company Accenture which has adapted this concept effectively describe 4PL as "*SC integrator that assembles and manages the resources, capabilities, and technology of its own organisation with those of complementary* *service providers to deliver a comprehensive SC solution*" (Fulconis *et. al.*, 2007; Yao, 2010). Figure 1.2 portrays 4PL concept explained by Accenture as a non-asset based integrator (Fulconis *et al.*, 2007).

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Figure 1. 2 4PL concept

Source: Fulconis et al. (2007)

The fig. 1.2 explains 4PL concept with contributions from the client organisation, the LSP and the network trading partners'. The client organisation supports the 4PL service provider by sharing their assets, working capital and operational expertise to manage and control the SC. In turn, 4PL service provider provides the information related to storage and movement of products by combining best practices, benchmarking and customer service management with the network members. In principle, the choice of 4PL is considered as a long-term strategic decision from the buying organisation's point of view. This can save a lot of resources in SC operations due to the *best of breed* approach (Fulconis *et al.*, 2007; Richey *et al.*, 2009). Based on the critical review, Accenture's definition of 4PL is considered in this thesis for further research. Thus, 4PL manages the entire SC centrally as a neutral agent by combining processes, technology and management (Mukhopadhyay and Setaputra, 2006). Consequently, 4PL aims at enhancing value proposition to the buying organisation compared to cost reduction in 3PL. Further, upgrading

LSPs with value added services to become 4PL requires a collaborative relationship with the buying organisation (Fulconis *et al.*, 2007). This criterion along with the management capabilities to drive change across the network members (van Hoek and Chong 2001) differentiates 4PL from other service providers. Therefore, an effective collaboration is deemed as an important value creation factor for 4PL service provider (Naesens *et al.*, 2007). Kutlu (2007) reported that 4PL implementation takes anywhere between three months to five years and recommends the implementation of 4PL in a phased manner. The criticality of 4PL deals with combining the benefits of outsourcing and in-sourcing to achieve local economies of scale in coordinating the SC (Win, 2008). 4PL service providers collect, manage and coordinate information to arrive at the most efficient SC solutions in a given situation. For instance, UPS and Ford have entered into a similar 4PL arrangement in USA (Kumar, 2008). Thus, the impetus for 4PL service provider to develop agile and cost-efficient distribution network (Kumar, 2008; Mody, 2009; Maha, 2009) is looked as a viable proposition. Further, 4PL ensures continuous supply of materials in the manufacturing process to meet end customer requirements proactively (Maha, 2009) by minimising risk. Hence, 4PL with analytical ability and experience is explored as an end-to-end SC solution provider (Zollo and Winter, 2002; Visser, 2007).

Chen and Su (2009) have advocated synthesising 4PL models for application in a practical scenario which extends the knowledge domain in logistics research. The automotive industry is regarded as a leading 4PL user and it is found that the transaction costs decrease whenever trading partners with high asset specificity collaborate (Hingley *et al.*, 2011). The asset specificity of a client organisation or service provider deals with the application of the resources for alternative purpose by the same or other users. For instance, General Motors entered in to an agreement with Menlo Logistics to form a 4PL company called Vector SCM (Walsh *et al.*, 2001). This company acts like a link between the client organisation and the network members by providing a single point of contact. The results revealed 75% performance improvement through reduction in order cycle time and SC costs (Hingley *et al.*, 2011). This thesis deals with an objective approach to measure 4PL value from operation's perspective which focuses on efficiency results along with cost reduction.

4PL has to keep abreast with changing dynamics of industry as some of the best practices today can become obsolete in the future (Gattorna, 1998). For instance, outsourcing is over taken through collaborative buyer-supplier procurement in the current business environment. Therefore, the client organisations are looking for 4PL service providers with core competencies in identifying and delivering customised solutions (Kutlu, 2007). The main functions of 4PL include planning and coordination of information flows, designing SC and combining inter-organisational information structure to manage the global distribution networks (Fulconis *et al.*, 2007; Kutlu, 2007). Besides, managing commodity purchases, payment to suppliers and negotiation of the contracts with LSPs to maintain just-in-time delivery are identified as the main operations of 4PL (Fulconis *et al.*, 2007). Conversely, 4PL vendors demand higher fee by achieving better savings to the client organisation and share risks by signing gain share agreements. Moreover, client organisation should contemplate before handing over the complete SC control to the 4PL service providers. Hence, a mathematical model which can combine the competencies of trading partners by enabling transparency between the client organisation and the 4PL service provider is warranted. As the 4PL relationship is complex, Kutlu (2007) proposed a theoretical framework in fig. 1.3 highlighting 4PL developments.

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Figure 1. 3 4PL theoretical framework

Source: Kutlu (2007)

The author identified four elements in the framework: "*Motives for Utilising 4PL*", "*Relationship Management and Strategic Development*", "*4PL Models, Supplier-Client Selection" and "Drawbacks* and *Risks of Utilising 4PL*". The 4PL vendor is placed between the client organisation and the physical service providers. In fact, the 4PL service provider is viewed as the client for third-party service providers. To put it succinctly, a buying organisation outsources the activities through 4PL service provider. Thus, the relationship between the trading partners is deemed as an important element to coordinate between other three elements of the framework. One interesting findings from Kutlu's (2007) study revealed that high cost of utilising 4PL did not seem to be a burden for the client organisation. The motives for utilising 4PL as reported in literature are cost reduction, value addition, elimination of 3PL problems, transparency in information flow, lean and responsive SC with cooperative environment to conduct business (Kutlu, 2007). Therefore, the client organisation looks for delivery and cross-segment integration capabilities as key skills before selecting the 4PL service providers (Win, 2008). 4PL streamlines the distribution network by adding value to their business processes through a single-point of contact (Visser, 2007; Win, 2008). Stank *et al.* (2011) reported knowledge gaps with respect to integration of trading partners, performance metric alignment and information availability in SC. Specifically, a dashboard framework with dynamic capabilities to measure value additions from the cross-segment integration is warranted. Besides, the authors called for a paradigm shift to expand the frontiers of traditional logistics research considering precision and accuracy of the attained results. By doing this, the buying organisation and the 4PL service provider can be aware of different scenarios for performing integration by mutually supplementing each other's competencies as well as complementing the inadequacies of trading partners.

4PL coordinates between trading partners and management consultants (ICFAI, 2003) by making critical decisions among the constellation of firms for hassle-free SC operations. In order to create this type of setting, the 4PL decision making unit is placed at the centre, known as transaction centre, which can monitor the product and information flow (Fulconis *et al.*, 2007). The transaction centre can be defined as an "*organisation which can manage large complex transactions, grouped and staggered in time and space with high customisation*" (Fulconis *et al.*, 2007; Gille, 1994). Specifically, the transaction centre is the place which facilitates cross-segment integration of independent trading partners with same strategic intent (Naesens *et al.*, 2007). Conversely, Fulconis *et al.* (2007) and Win (2008) summarised transition in dynamics of logistics industry to brokerage oriented culture. Thus, 4PL with the transaction centre approach aggregates chain partners with decision making autonomy. Visser (2007) characterised transaction centre as "*4PL platform which acts as a single-point integrator*". Moreover, the transaction centre acts as a hub to carry out the dedicated activities of logistics and distribution (Minnaar and Vosselman, 2013). Antai and Olson (2013) highlighted the scarcity of resources for critical operations due to the competition between SCs. Therefore, the authors have proposed a transaction centre in fig. 1.4 where SCs interact in a common platform to share resources and competencies to achieve common goal. Thus, the capabilities of transaction centre can be evaluated based on the operational resources and competencies that the 4PL vendor possesses.

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Figure 1. 4 Interaction between SCs in transaction centre

Source: Adapted from Antai and Olson (2013)

Transaction centre can be common, specialised, local or global to facilitate value adding process in the 4PL network (Fulconis *et al.*, 2007; Antai and Olson, 2013). As SC trend is looking for reduction in inventory, warehouse downsizing and wider range of competencies with limited time (Evangelista *et al.*, 2013); transaction centre suffices the requirement by facilitating coordinators. The 4PL coordinator controls the transaction centre by combining resources, assets and competencies of various trading partners (Gille, 1994). In particular, the transaction centre can be used for coordinating 4PL activities by sharing best practices. Besides, emphasis on integration role of cross-segment mergers is looked as a critical activity (Antai and Olson, 2013). Therefore, transaction centre plays a vital role by adding value to the buying organisation's SC and it is viewed as an integral part of 4PL activity.

Development of 4PL transaction centre relies on dependence, spill over and conservatism risks (Visser, 2007). Investments made in the 4PL network imply dependence among the trading partners. However, the positive impact of investments is lost if the trading partner is subjected to opportunistic behaviour from other parties. The investment may be in the form of physical assets, people etc. Thus, there is a possibility of dependence risk for either party in a 4PL setup due to the power imbalance (Visser, 2007; Habib *et al.*, 2015). Here, the dependence of one trading partner on the other is a function of relative dependence (Habib *et al.*, 2015). Further, risk of dependence is measured from buyer's or trading partner's perspective utilising gross or net dependence respectively. Gross dependence deals with dependence of trading partners on the buying organisation. Net dependence implies a degree of reliance on trading partners by the buying organisation (Visser, 2007). The author suggested the mitigation of dependence risk through balancing, compensation and eliminating sources of transaction cost through strategic alliances. Balancing refers to cooperative behaviour between cross-segment trading partners. Compensation refers to executing long-term supply contracts. IT may be considered as one of the source for eliminating transaction costs across the value chain. In 4PL, the knowledge exchange through cross-segment integration may lead to unnecessary loss of intellectual property. This is termed as spill over. For instance, a LSP might work with the client organisation's competitor leading to transfer of best practices. This spill over risk can be addressed by enabling the trading partners to sign confidentiality agreement and the client organisation should be willing to share the accrued benefits. Lack of awareness with regard to the advantages of cooperative relationship, globalisation and holistic view to utilise resources have led to conservatism risks in a 4PL network. The order of risks reported by Visser (2007) are conservatism as first, dependence as second and spill over as third. Besides, mitigation of these three risks are recommended through learning, innovation and dynamic transaction cost theory apart from IT (Mukhopadhyay and Setaputra, 2006; Visser, 2007). Thus, the 4PL transaction centre should comprise of research-based innovative models to design and implement comprehensive SC solutions (Mukhopadhyay and Setaputra, 2006; Visser, 2007).

The primary role of the coordinator of transaction centre is to ensure transparency and coordination between trading partners. Further, the ability to combine outside competencies with internal resources to create post-merger synergies is considered as the evaluation parameters (Visser, 2007). Fulconis *et al.* (2007) proposed the 4PL concept with transaction centre perspective which aggregates competencies of trading partner to become a backbone of the network organisation. In addition, 4PL transaction centre enables all the actors of SC to share critical information with each other. In parallel, the transaction centre performs planning and coordination across chain partners to re-design and optimise the client organisation's SC with decision making autonomy. Forslund and Jonsson (2007) identified that arriving at standard metrics for cross-segment integration and setting benchmarks as important activities of the transaction centre. In general, the main role of intermediaries are aggregation, balancing and facilitating network members to enable trust (Bailey and Bakos, 1997) for cross-segment integration. The transaction centre has to play a dual role of mediator and IT integrator among constellation of firms (Fulconis *et al.*, 2007). Conversely, most of the 4PL vendors provide advice but may fail to deliver solutions (Kutlu, 2007). In addition, integration activity in a 4PL setting is deemed as a research frontier and needs an in-depth analysis (Yao, 2010). Moreover, the coordinator of transaction centre needs to provide plug and play solutions to act as a single-point integrator (Ogulin *et al.*, 2012; Kiessling *et al.*, 2014).

However, the scarcity of information on 4PL development has led LSPs to go slow on upgrading their services considering risk parameters (Visser, 2007). Besides, strength and value adding capacity of 4PL is linked to selecting and coordinating the right set of cross-segment trading partners (Eg: suppliers and LSPs) in the transaction centre (Fulconis *et al.*, 2007; Visser, 2007). In addition, a range of services that the neutral 4PL transaction centre provides is considered as vital (Schmoltzi and Wallenburg, 2011; Antai and Olson, 2013). Even though 4PL research has emphasised on the importance of transaction centre, literature on exact operating framework appears to have not been dealt with. Taking cue from limitations, a dedicated 4PL transaction centre that can deal with a range of cross-segment mergers to provide new capability operating standards is proposed to support SC operations.

In this thesis, notion on 4PL development is based on the comprehension of transaction centre operating principles for cross-segment integration. The 4PL conceptual model developed by Win (2008) identifies Economic Value Added (EVA) as an appropriate measure of value creation, but EVA has little engineering meaning. Most of the literature report that the 4PL deals with *best of breed* trading partners but how these trading partners are made *best of breed* is not reported (Kutlu, 2007). This thesis differs from the existing research which portrays one step backwards to build *best of breed* trading partners. This motivated to develop an exclusive 4PL performance measurement framework that evaluates network members along with providing suggestive directions for improvement in creating a *best of breed* setup. In addition, assimilation of transaction centre and evolving standards for merging trading partners is not addressed. Moreover, the 4PL transaction centre acts as a single point integrator which can utilise assets of trading partners effectively, exchange information and develop trust through mutual co-operation (Fulconis *et al.*, 2007). Factors such as these are recognised but not addressed in the research-based innovation models (Visser 2007; Mukhopadhyay and Setaputra, 2006). Thus, there exists no available (commercially or otherwise) transaction centre model that can deal with range of cross-segment integration of trading partners to support 4PL operations. In parallel, Leeuw and Fransoo (2009) found no synchronous view in the literature with regard to cross-segment integration of trading partners. Thus, research based models considering uncertainty situation are stressed based on the available literature (Tejpal *et al.*, 2013). Hence, a procedure to synthesise transaction centre for carrying out cross-segment mergers is considered necessary to enable smooth functioning of 4PL. Therefore, a proven model of 4PL transaction centre from operation's point of view needs to be formulated and validated. For this reason, development of transaction centre model that can provide operating standards for integration process is conceived.

Key issues addressed in this thesis are implementation characteristics and monitoring integration process by the 4PL transaction centre (Fulconis *et al.*, 2007; Visser, 2007). Thus, the transaction centre for evaluation and integration of trading partners is proposed, modelled, implemented and verified. This has led to the problem formulation in the form of development of an exclusive 4PL approach to evaluate trading partners and integrate the improved competencies of trading partners in a dynamic transaction centre. As the 4PL coordinator needs to effectively manage SCs, a holistic approach to organise activities of transaction centre through specialised competencies is warranted. This thesis presents modelling of the 4PL transaction centre considering performance and cost perspective which involves collecting data, analysing and reporting the findings through proper validation. Mathematical models in SC should capture the behaviour of distribution network by involving all the network members (Janssen and Sol, 2000). In addition, the authors reported that no standardised models or frameworks are available for managers which can suit a particular company. Also, model building approach should provide scope for answering '*what-if*' analysis. Thus, empirical research in SCM is more about theory building (Soni and Kodali, 2011) which helps the researcher to understand the complex situation in a scientific way (Chicksand *et al.*, 2012). This thesis builds on the theoretical development of Fulconis *et al.* (2007) framework by extending Bogetoft and Wang's (2005) production economics model. Therefore, proposing a new model of 4PL transaction centre by addressing the challenges related to its implementation and practices contributes to the theoretical development of SCM.

In this thesis, modelling of the 4PL transaction centre is carried out by identifying the contemporary performance measures of SC since it is cumbersome to arrive at a single performance index in MCDM environment (Green, Jr. *et al.*, 2008; Shafiee *et al.*, 2014). Soni and Kodali (2011) reported from the comprehensive review on SC performance measures that positive trend exists in developing the new frameworks at advanced levels by identifying limitations in the existing empirical studies. As the research study of this thesis focuses on operations perspective, an appropriate objective measure is needed to arrive at a single overall performance index along with the capability to provide suggestive guidance for improvement of individual trading partners. Thus, the computationally efficient Data Envelopment Analysis (DEA) technique is considered as an appropriate methodology which derives optimal weights from the data, thus, making it an objective approach (Cooper *et al.*, 2007). Besides, these derived weights can also be used for benchmarking among similar category of network members. In principle, DEA approach can analyse multiple inputs and outputs simultaneously in order to arrive at a single overall performance index (Wong and Wong, 2008). Thus, evolving a suitable mathematical model using DEA technique for SC evaluation is depicted as the future direction of research. In particular, existing DEA models with modifications is deemed as an appropriate performance measure for comprehensively evaluating the SCs (Chen, 2009; Wong and Wong, 2008). Above all, this approach can be integrated with other methodologies like statistics and econometrics to connect engineering and economic approaches (Charnes *et al.*, 1978; Chen, 2009). DEA can also be mathematically represented as the ratio of weighted sum of multiple outputs to weighted sum of multiple inputs by ensuring that the efficiency score lies between zero and one (Jalalvand *et al.*, 2011; Shafiee *et al.*, 2014). This thesis proposes the modelling of transaction centre through a DEA approach considering time dynamics as an influential factor instead of conventional static evaluation. In order to model a transaction centre that has the capability to select *best of breed* trading partners and conduct cross-segment integration with desired accuracy and precision for effective 4PL operations, the warranted further research encompassing the following aspects are undertaken:

Evaluation of Trading Partners for Synthesising *Best of Breed* 4PL Setup:

It is necessary that the 4PL service provider should be neutral (Mukhopadhyay and Setaputra, 2006) to benchmark performance of trading partners' in order to create a *best of breed* setup. Hence, an exclusive 4PL performance measurement framework which considers both buyer and trading partner perspectives (Hammervoll and Toften, 2010; Wu and Barnes, 2012) is warranted in a practical scenario with the following features:

- A pre-requisite approach to identify *like-minded* network members for 4PL development in order to examine possible strength in the relationships for further DEA evaluation from trading partner perspective
- Multi-stage DEA performance evaluation framework comprising of dynamic characterisation which can assimilate individual trading partner capabilities along with identifying the sources of inefficiency from buying organisation perspective

Cross-Segment Integration Framework for 4PL Transaction Centre:

To achieve economies of scale and optimal mergers, cross-segment integration process is employed to combine the competencies of third parties. Specifically, interactions between various categories of trading partners in the transaction centre escalate the 4PL business practices from competitive to cooperative environment (Antai and Olson, 2013). The standardised cross-segment integration framework for the 4PL transaction centre with following features are required:

- Extension of the production economics integration model from conventional similar-segment mergers to cross-segment mergers with respect to operation's view point that can quantify the optimal merger gain
- Necessary and sufficient conditions that can facilitate coordinators of transaction centre to deal with multi-criteria decisions objectively along with risk considerations in order to exhibit strength and applicability of the 4PL network

The focus of the proposed thesis is to model a 4PL transaction centre by addressing and resolving the research issues listed under both evaluation and cross-segment integration sections. By virtue of these issues, the araising Research Questions (RQs) along with aim and objectives of the proposed work are reported in the next section.

1.1.1 Research Questions and Objectives of the Thesis

4PL represents next generation logistics which aims at enhancing value addition to the buying organisation rather than cost reduction. Specifically, 4PL provides end-to-end SC solutions wherein deliverable intricacies of value addition are worth further investigation due to its infancy stage (Win, 2008). At the same time, differentiation of 4PL is directly proportional to the inherited expertise and analytical capabilities that the transaction centre possesses (Visser, 2007). Hence, development of 4PL is dependent on the operations of transaction centre which integrates cross-segment trading partners. 4PL transaction centre presents many additional challenges; main ones being implementation characteristics and monitoring cross-segment integration (Fulconis *et al.*, 2007; Visser, 2007). However, the 4PL service providers' role to implement transaction centre is not well explored. Conversely, there is a scarcity of exclusive

4PL cross-segment integration framework to ascertain the viability of mergers which does not ignore dynamic capabilities in logistics literature (Naesens *et al.*, 2007; Su *et al.*, 2011; Brekalo *et al.*, 2013). In order to become a single point integrator, the transaction centre has to acquire new competencies for evaluation and integration of trading partners. Another research aspect of equal significance deals with sustainability of the attained mergers which is linked to dependence among the trading partners and risks anticipated (Sarkis *et al.*, 2007). Moreover, the number of 4PL service providers is going to be scarce in the future due to the associated risk factors (Visser, 2007). Despite these contradictions, the LSPs have reached a position to add fourth-party services into their portfolio. Thus, a transaction centre model which can integrate cross-segment trading partners in a standardised approach is necessary to enable transparency between the client organisation and the 4PL service provider.

By virtue of the above mentioned research perspectives, this thesis addresses the following questions:

1. Given a shift in logistics trend to brokerage oriented culture, what are the modifications necessary to model 4PL transaction centre from operations perspective?
2. Given such a transaction centre model, can the developed model be imparted the capability to evaluate, improve and sustain post-merger effects across different categories of trading partners?
3. Can the proposed model be used in a real-time 4PL business practices and will such a model be extended to solve industry specific problems along with risk consideration?

This thesis envisages addressing the answers of the above listed RQs through the following aim and realisation of listed objectives:

Research Aim:

To model an effective 4PL transaction centre which can evaluate trading partners and comprehensively integrate the improved competencies of trading partners for sustaining the post-merger effects

Objectives:

1. Review of literature pertaining to third-party operations process and 4PL implementation characteristics and collection of data

2. Categorisation of trading partners as a standardised pre-requisite approach to utilise DEA principles in SC environment by estimating net dependence effect using analytical methods
3. Analysis of trading partner performance using DEA under static and dynamic considerations to develop a *best of breed* 4PL setup in order to leverage integration
4. Creation of 4PL transaction centre model that can be used to optimally integrate cross-segment trading partners and provide operating standards for mergers
5. Extensions to the proposed transaction centre for enhancing applicability of the model in a practical scenario along with risk considerations
6. Evaluation of the transaction centre model through data variation and verifying the model using sensitivity analysis for examining the feasibility through real-time 4PL business practices

In this thesis, RQ-1 is answered through objectives 1 and 2 which address pre-requisite operational modifications necessary for modelling the 4PL transaction centre. RQ-2 is realised by achieving objectives 3 and 4 for performing trading partner evaluation to create a *best of breed* 4PL setup along with the capability to conduct optimal cross-segment integration in the proposed transaction centre. Finally, RQ3 is envisaged to be addressed through objectives 5 and 6 by demonstrating extensions to the recommended model, as well as, analysing disruption risks with respect to real-time 4PL business practices. In the subsequent section, realisation of objectives in the form of thesis summary is reported.

1.1.2 Thesis Summary

In this thesis, the transaction centre that can provide new capabilities for 4PL operations is modelled. Specifically, the operational challenges in the form of '*creating a best of breed trading partner setup*', '*standardisation and control of integration*' and '*aligning resources to develop synergies*' are presented. In parallel, a tractor and tiller manufacturing company is selected as a case study to validate the research aim. Moreover, every contribution of this thesis is demonstrated utilising real industry data of various categories of suppliers and LSPs. Conversely, the selected company is exploring opportunities to maintain its leadership position in India due to the increased pressure from competitors in the current scenario. Thus, adopting

4PL service provider is looked as one of their projects to improve operational efficiency by the proactive management of supply.

Initially, an exclusive 4PL performance measurement framework to create a *best of breed* setup is proposed from the trading partner and buying organisation perspective in a balanced approach. A pre-requisite setting is proposed to reduce the size of the SC problem for utilising DEA principles. The goal of this pre-requisite approach is to cluster heterogeneous trading partners into *like-minded* groups. Here, the interaction based parameters are explored for estimating net dependence using analytics from trading partner perspective prior to performance evaluation. Results from the recommended approach yielded strong positive relationship across *like-minded* trading partners. The generic and the versatile features of this approach are demonstrated by eliminating single-sided dependence among network members and its application can be extended to other areas of DEA evaluation. Subsequently, an integrated multi-stage DEA framework is developed considering time dynamics as an influential factor to avoid bias in the evaluation process. The recommended framework comprises of discretionary, non-discretionary and categorical formulations along with dynamic characterisation by combining DEA and econometric models. The dynamic characterisation is realised through variable lag effect (positive, neutral or negative) on the subsequent chain partners instead of conventional static DEA evaluation. In this scenario, the transaction based parameters are utilised for identifying input-output parameters to conduct DEA evaluation of trading partners from buying organisation perspective. Evaluation of the intended performance measure is carried out through data variation and validated through non-parametric statistics signifying required level of precision and accuracy. The developed performance evaluation framework has revealed that static evaluation overestimates dynamic consideration by 4% to 5%. In addition, the suggested dynamic system yielded better DEA results with increase in number of efficient units, average efficiency (~23%) and standard deviation (~38%). The developed performance measure is proved to be effective with output disposability relaxation assumption on lagged effects wherein the resultant framework can be generalised to any industry. This type of multi-stage framework makes the performance evaluation model pragmatic by helping the coordinator of 4PL transaction centre to portray '*AS-IS'* and '*TO-BE'* conditions for benchmarking trading partners.

Based on the projected evaluation scores, this thesis proposes a standardised cross-segment integration framework for modelling the 4PL transaction centre that can deal with a range of mergers (Example: suppliers and LSPs) to provide operating standards. The merger gain of cross-segment integration is quantified in a two-tier approach prioritising performance orientation in the first tier and cost orientation in the second tier. For enhanced consistency and adequacy of model, mean and variance statistics between the actual situation and the suggested model is critically analysed with regard to the conceived operating standards for mergers. Also, statistical fundamentals of efficiency distribution are established with quantified confidence to achieve improved process control of the attained mergers. Verification of the proposed model is conducted through stability and sensitivity analysis for the attained mergers. Further, empirical results from the proposed transaction centre model of 4PL showed 18% to 43% cost savings. In principle, the thesis presents and demonstrates an objective approach to quantify 4PL value addition in a unified approach (evaluation and integration) apart from EVA. The thesis also substantiates SC system analysis, design and planning by analysing post-merger effects. By virtue of this model, buying organisation opting for 4PL can know the capabilities of individual network members to synchronise outside competencies with internal resources.

In order to claim applicability of the model, distinguished features and characteristics are embedded as extensions to the 4PL transaction centre under MCDM environment. Specifically, capabilities to deal with sub-optimal 4PL solutions, trade-off between policy decisions and system constraints, and grouping trading partners with respect to delivery time are analysed. In order to estimate 4PL risk proactively, an exclusive risk assessment and predictive model for the transaction centre is developed. Besides, the proposed risk model foresees supply risks proactively before integrating cross-segment trading partners for consistent 4PL operations. This thesis finds its utility by assisting the coordinator of transaction centre to manage and control the activities of 4PL. In summary, the realised improvements from the recommended transaction centre have revealed significant value additions in the form of cost reduction, assimilating net dependence among network members, arriving at operating standards for mergers, estimating risk proactively and infusing trust across the value chain. Also, the proposed model delivers transparent solutions by influencing cooperative relationship across the value chain contributing to the theoretical advancement. In the next section, implication of the research study is presented.

1.2 Implications of the Research Study

The perceived governance structure of the proposed transaction centre model facilitates the 4PL service providers to proactively understand the SC requirements of buying organisation from operations perspective. The recommended model selects the *like-minded* network members and evaluates them in a multi-stage framework along with providing suggestive improvement directions for individual trading partners to create a *best of breed* 4PL setup. The proposed model enables the coordinator of 4PL transaction centre to deal with discretionary, non-discretionary, categorical and dynamic situations to emulate actual scenario in a multi-stage framework by eliminating bias in the evaluation process. With a clear understanding of the capabilities of individual network members, the coordinator of transaction centre can integrate the competencies of these different categories of trading partners in the form of cross-segment mergers to achieve economies of scope and scale for developing post-merger synergies as a neutral agent. Subsequently, the 4PL coordinator can consider various aspects in multiple domains as extensions to the proposed transaction centre model for dealing with multi-criteria decisions along with risk considerations in order to address real-life industry problems.

The primary responsibilities of the proposed 4PL transaction centre is to provide customised SC solutions to the buying organisation in alignment with their corporate strategy. Moreover, the 4PL transaction centre has to manage individual SC as a separate account for managing long-term relationship with different categories of trading partners. Due to the interdependence among network members, developmental growth of the individual trading partners is achieved simultaneously for handling upstream and downstream SC uncertainties by supporting collaborative initiatives across the 4PL network. To put it succinctly, the 4PL transaction centre must be flexible, neutral and act as a single-point integrator to provide comprehensive SC solutions by insisting inevitable and yet desirable change for the ever-changing business environment. In fact, the key differentiator of 4PL transaction centre with respect to competition is that it starts as a lead logistics provider for the buying organisation. Subsequently, it takes control of the SC in an incremental way to emerge as a solution integrator for a particular industry with the passage of time. By deriving broad industry standards, the transaction centre can benchmark respective trading partners and provide holistic solutions for a particular industry capturing best practices along with emerging trends to add value for the 4PL network. Based on the trend of logistics industry (Win, 2008; Fulconis *et al.*, 2007), the types of organisation which could conceivably manage such a 4PL transaction centre are major LSPs and consulting firms like UPS, DHL, Kuehne & Nagel, Accenture, e-logistics, TVS Logistics who can manage people, process and technology as a non-asset based integrator.

In this thesis, modelling of 4PL transaction centre that can comprehensively integrate the competencies of third parties by identifying evaluation and integration of trading partners as main issues are developed. Conceptually, "evaluation" and "integration" differ only in the time of decision making process (Chen, 2009). Further, significance of the created model for 4PL business practices emphasising on the information that should be collated and analysed are discussed. This thesis has contributed to the advancement of both theoretical aspects as well as applications point of view to support 4PL operations. Due to the infancy situation of 4PL, the approaches proposed in the thesis can be used to review, improve, and sustain post-merger effects in the transaction centre effectively. In the next section, description of organisation of the chapters are documented.

1.3 Organisation of Thesis

The thesis comprises eight chapters which deal with modelling 4PL transaction centre along with its extensions. In chapter-1, an introduction to 4PL business practices with the transaction centre perspective is discussed followed by motivation for modelling. Chapter-2 presents critical review of literature on 4PL transaction centre and SC performance measures. Chapter-3 formally elucidates the methods and methodologies adopted in the thesis to accomplish objectives of the proposed research. Rationale, assumptions and parameters, formulation for the development of the proposed model of 4PL transaction centre are presented in chapters-4 and 5. Additional features are embedded as extensions in chapter-6 to make the intended model robust. Chapter-7 deals with an exclusive 4PL risk model which can mitigate supply disruptions proactively and the transaction centre can be managed effectively. Chapter-8 consolidates concluding remarks and recommendations for future research based on analysis of significance of the results obtained as well as inferred limitations of the proposed approaches.

CHAPTER 2: 4PL TRANSACTION CENTRE - LITERATURE REVIEW

2.1 Current Logistics and SCM Challenges

With globalisation trends, organisations are looking at cost reduction (Chen and Su, 2009; Lieb, 2008) and improved service level (Visser, 2007) to increase their competitiveness. Erstwhile organisations used to concentrate on their core competencies which led to the reduction of new product development costs and operations lead time. However, organisations have already benefited by adopting principles like Total Quality Management and Just in Time (ICFAI, 2003). Currently, organisations are focusing on non-core competencies for further improvements (Win, 2008). This has resulted in the emergence of logistics and SCM concept. Multi-national companies are already looking at improving global competitiveness by focusing on SCM as one of their critical enablers (Visser, 2007). Due to parallel developments in the area of agile manufacturing and SC, organisations need to continuously re-design and re-engineer their network in order to operate in a competitive environment (Fulconis *et al.*, 2007). Chopra and Meindl (2007) and Visser (2007) further asserted that SCM makes it imperative for the trading partners to co-operate with respect to a common goal in order to increase overall efficiency and effectiveness across the distribution system. Richey *et al.* (2009) highlighted that co-operation among network members belonging to the same SC is recognised as a powerful source of competitive advantage. Recently, the concept of green SC is under focus due to the tightened environmental regulations in the product life cycle which includes sourcing, manufacturing, distribution and recycling of end life products (Chen, 2009; Gopal and Thakkar, 2012). Since, logistics is considered as one of the critical decision levers in SCM (Chopra and Meindl, 2007); critique on opportunities and challenges in logistics domain are addressed in the next paragraph.

With enormous infrastructure projects underway through public-private-partnerships and Government allowing 100% foreign direct investments in logistics industry (Kumar, 2008), there are huge opportunities for LSPs in India (Lieb, 2008). It is clear that the prospects for the 3PL industry looks optimistic as the development of infrastructure projects like building highways, ports and special economic zones require these services to schedule resources optimally. However, inventory stocks in Indian supermarkets vary up to 45 days compared to 14 days in

Thailand and one or two days in Europe (Kumar, 2008). 3PLs are positive in maintaining the relationship with buying organisations but lacks integration capabilities (Kutlu, 2007), thus, creating a vacuum. This led to the emergence of 4PL which can manage the entire SC based on client organisation's requirement (Sahay and Ramaneesh, 2006). In general, 4PL allows companies to achieve profitability faster and allows the organisation to focus on their core competencies (Kutlu, 2007). Thus, 4PL is deemed as a single point integrator to manage the logistics process optimally (Chen and Su, 2009; Richey *et al.*, 2009).

The concept of 4PL is an outcome of logistics process innovation (Flint *et al.*, 2005) which acts as a non-asset based integrator. This makes 4PL an integration specialist which plays a decision making role in the common platform (Visser, 2007). Integration concept deals with finding and merging appropriate trading partners for delivering products consistently to satisfy end customer's requirements (Fulconis, *et al.*, 2007). Nonetheless, a detailed understanding and frequent interactions with all the trading partners of the network is warranted to enable transparency, trust and cooperative relationship in the SC (Kwon and Suh, 2005; Claro and Claro, 2011). This leverages all the trading partners to comprehend the client organisation's requirement. Furthermore, 4PL service providers should be in a situation to identify the problem and deliver the solutions effectively (Kutlu, 2007). In addition, 4PL service provider and trading partners should inculcate a habit of flexibility with a positive approach to create a *win-win* situation (Win, 2008). Conversely, organisations look for standardised and structured services from the 4PL vendors (Mortensen and Lemoine, 2008). Thus, 4PL represents next generation of logistics (Win, 2008) whose intervention has to be critically analysed with respect to the real world scenario. In parallel, large companies utilise 4PLs to avoid compatibility issues between cross-countries (Tejpal *et al.*, 2013). This is one of the areas where 4PL development is linked to become real legitimacy in the domain of logistics (Fulconis *et al.*, 2007; Kutlu, 2007).

2.2 Need for 4PL

Before understanding the concept of 4PL, background theories of logistics, SCM and outsourcing provide a strong foundation (Kutlu, 2007). According to Gattorna (1998), insourcing is the trend during 1970s; outsourcing all through 1980s and 1990s, and evolution of 4PLs from later half 1990s to early 2000. The next level of logistics which deals with information integrated material flow is known as SCM. The integrated SC embraces a shift in adversarial relationship towards mutual cooperation and co-development focusing on customer requirements. Multiple SC services provided by a single vendor at a competitive cost is termed as outsourcing (Kutlu, 2007). In order to keep abreast with the competition, 3PLs evolved by utilising its asset effectively (Kutlu, 2007). Due to the transition towards brokerage oriented culture (Fulconis *et al.*, 2007; Win, 2008), a paradigm shift from 3PL to 4PL emerged in the logistics industry (Kumar, 2008). Thus, 4PL acts as an integrator which combines synergies to deliver value to the customer (Fulconis *et. al.*, 2007). Win (2008) highlighted that 4PL value can be interpreted depending on whose perspective it is assessed and the ability to impact the entire SC. van Hoek and Chong (2001) reported 4PL responsibility and divide to deal with buying organisation and trading partners with reference to UPS worldwide logistics as depicted in fig. 2.1.

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Figure 2. 1 4PL responsibility and divide

Source: Adapted from van Hoek and Chong (2001)

4PL interacts with the buying organisation for designing SC strategy to re-engineer their business model through collaborative process development. The 4PL service provider brings in SC experience to a common platform in order to provide optimal solutions by combining competencies of network members. This influences different categories of trading partners to coordinate each other for satisfying client organisation's requirement. The authors further characterised 4PL's initial focus as redesigning the distribution network using the existing *best of breed* trading partners. In future, IT and 4PL can combine their competencies to provide innovative and customised solutions to the client organisation. Following the concepts, 4PL is characterised as a complete business process outsourcing service provider. However, Su *et al.* (2011) highlighted scarcity in theory development of innovative processes in SC literature which deals with "*How to accomplish the desired goal*?" Flint *et al.* (2005) reported the logistics innovation process model as shown in fig. 2.2. The dynamics for innovation process starts with setting a common platform to coordinate between different categories of trading partners leading to inter-organisational learning. By understanding the individual strengths and weaknesses, the trading partners can deal with their limitations by collaboratively sharing resources. In fact, this process is iterative and can be continued till the trading partner is willing to stay in the 4PL network. By virtue of mutual learning, logistics innovation can be attained to satisfy the unflagging need of the buying organisation in the current business environment. In summary, logistics innovation process comprises of setting up a platform to coordinate the activities; comprehensive data collection for process analysis along with feedback and continuous improvement.

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Figure 2. 2 Logistics innovation process

Source: Flint et al. (2005)

Visser (2007) further supported that 4PL is a result of logistics innovation which provides research based advice to implement effective SC solutions for large enterprises. For instance, *Vendor Managed Inventory* concept is one such innovation conceived by a 4PL service provider (Wisner *et al.*, 2005). More than 90% of the respondents from the end user study conducted by Win (2008) cited that 4PL has emerged as an ideal solution for wide variety of companies through one stop accountability across supply and demand chains. In summary, 4PL elevates the effects of SCM along with adding value to the business (Cheng *et al.*, 2008).

4PL service providers have drawn a lot of attention which basically design and sell global solutions to integrate the competencies of different category of trading partners (Bauknight and Bade, 1998). 4PLs advise client organisation for coordinating SC activities and procurement of apt software solutions. In principle, 4PL service providers are considered as a true catalyst to manage global SCs that extend well beyond traditional LSPs (Visser, 2007). Further, differences between 3PL and 4PL are documented by Visser (2007) in table 2.1.

Kittel (2003) implemented 4PL to four companies in Sweden and summarised the findings as follows:

- 4PL service provider proposes holistic solutions compared to 3PLs who look for their individual profit
- The holistic solutions enable 4PL to recommend broad industry standards which can help the organisations looking for similar activity
- 4PL can pool the competencies of different trading partners and provide customised solution based on the individual client organisation’s requirements

Fulconis *et al.* (2007) proposed three key propositions for 4PL development as follows:

1. Ability to provide globalised solution through consultancy
2. Information sharing for logistics flow monitoring through IT
3. Standardised architecture for enabling and controlling cross-segment integration

Table 2. 1 Differences between 3PL and 4PL

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Source: Visser (2007)

Cruijssen *et al.* (2007) found that horizontal cooperation in logistics enables profitability of organisations and improves quality of services. The horizontal cooperation has led to the emergence of 4PL which takes over the lead role for controlling transactions of the entire SC. Kutlu (2007) analysed the reasons for utilising 4PL from the client organisation perspective and reported Foster's (1999a) 4PL value propositions in fig. 2.3 as the chain reaction mechanism. By virtue of the 4PL service provider, enhanced product quality, reduction in inventory and operating cost, single accountability, decreased fixed capital and better customer service can be achieved. This leads to increased profitability, reduction in financial investments due to sharing of resources and increase in the shareholder value. Moreover, collaboration between all the trading partners is deemed to be an important challenge for 4PL.

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Figure 2. 3 The 4PL value proposition

Source: Foster (1999a)

Win (2008) highlighted key issues by implementing 4PL framework to two medium sized alcoholic beverage companies. The study provides insights to be considered before outsourcing to 4PL service provider. The main attributes that the client organisation's look for selecting the 4PL service providers are capability to coordinate network members, ability to perform cross-segment integration, single point of contact for accountability and initiating change management across the value chain. On the contrary steady growth, inventory pile-ups, re-alignment of business focus and in-effective forecasting are the main reasons for client organisations to opt for 4PL service providers. However, the asset based 3PLs assuming 4PL role might tend to maximise their asset utilisation portraying bias. In summary, the 4PL service provider should be neutral to all the trading partners which aims at adding value to the bottom line.

Richey *et al.* (2009) reported that 4PL operations deal with the integration of resources by assigning tasks to the *best of breed* trading partners. Further, Hingley *et al.* (2011) emphasised that trading partners should be willing to participate in the 4PL network and the time is right to expand the spectrum of 4PL domain knowledge. Moreover, 4PL service providers are capable of handling complex resource integration activities effectively and efficiently (Yao, 2010). In principle, 4PL manages the complete SC by combining the competencies of *best of breed* trading partners, technology service providers and consultants which cannot be achieved by 3PL alone (Kutlu, 2007; Lieb, 2008). In fact, 4PL service providers proactively look at the SC from client organisation's perspective and redesign the same for effective operations. Hence, 4PL should be proactive as compared to reactive 3PLs which can be attained through information sharing (Wieland and Wallenburg, 2013). To develop a proactive 4PL network, maintaining transparent relationship between the trading partners is considered as vital factor for enhancing operational performance (Richey *et al.*, 2009). For this reason, a common 4PL platform to integrate cross-segment trading partners in a standardised approach is necessary in the form of single-point integrator. Therefore, an exclusive transaction centre for 4PL which can combine the competencies of cross-segment trading partners is warranted to execute the integration operations optimally (Visser, 2007). In the next section, transaction centre and its importance in 4PL is elucidated from operations perspective. In addition, research areas from opportunities and hindrances of 4PL development are addressed to identify the theoretical gap.

2.3 4PL Transaction Centre

4PL service provider's primary role is cited as conducting cross-segment integration (Bade and Mueller, 1999) for a well-structured coordination of business operations. Moreover, the cooperative relationship leads to spill over of knowledge and enhancement of operational capabilities. By virtue of this, the trust among trading partners and standardisation of processes in the SC network can be achieved (Bourlakis and Bourlakis, 2005). In a 4PL setting, success of individual network member is derived based on the overall achievement of the SC, thus, leading to organisational success (Kutlu, 2007). But, infrastructure to facilitate such integration is not available. Thus, SCI is deemed as an important aspect in SCM research and its enablers are extensively studied by the researchers (Mortensen and Lemoine, 2008). Hence, 4PL should maintain cooperative relationship with their chain partners to become a single point integrator by combining the competencies of *best of breed* third parties. Jharkharia and Shankar (2007) identified that the compatibility between client organisation and 4PL is the key criteria to determine the relationship. Here, the selection of *like-minded* trading partners based on their interdependence between operational criteria helps the coordinator to enable SCI. This type of setting leads to innovation and the buying organisation can attain competitive advantage in the target market (Anderssen *et al.*, 2010). Moreover, different levels of integration relationships are appropriate for effectively managing the SC (Canto *et al.*, 2011). In addition, frequent two-way communication (Kwon and Suh, 2005) and teamwork (Prajogo and Sohal, 2013) are considered as the key competencies necessary for SCI (Wieland and Wallenburg, 2013). Therefore, SC collaboration which deals with two or more independent organisations adds value to the end customer. Coming together of these independent organisations for aligning SC is also called as cross-segment integration in this thesis.

In principle, the 4PL service provider is placed at the centre among constellation of firms known as transaction centre (Fulconis *et al.*, 2007). The main challenge of 4PL transaction centre is to act as an intermediary between the client organisation and the third-party service providers. Contrarily, the concepts such as strategic alliances and joint ventures have received enormous interest in the management literature (Cruijssen *et al.*, 2007). Net positive value from the merger outcome is considered as a driving force for individual trading partner to carry out cross-segment integration (Parkhe, 1993). Therefore, a holistic approach to coordinate the activities of transaction centre is warranted from operations perspective by assimilating the challenges of future. For instance, 4PL implementation phases at UPS worldwide logistics (van Hoek and Chong, 2001) is shown in fig. 2.4. The below figure highlights the change processes by implementing 4PL in different phases. Phase-A represents traditional third-party service providers; phase-B establishes the 4PL setup for coordination between LSPs. Similarly, phase-C has an intermediate layer known as the transaction centre between client organisation and various trading partners. Finally, Phase-D captures the contemporary 4PL transaction centre scope which has access to entire information of the SC.

4PL transaction centre's value is analysed through service level, quality, cost and consistency. In particular, the transaction centre acts as a SC control room to manage 4PL activities effectively to attain collaboration (Christopher, 2005).

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Figure 2. 4 Implementation phases of 4PL at UPS worldwide logistics

Source: Adapted from van Hoek and Chong (2001)

In fact, collaboration between cross-segment trading partners negates opportunistic behaviour (Bourlakis and Bourlakis, 2005). Fulconis *et al.* (2007) explained the strategy dynamics of 4PL through the transaction centre approach highlighting the cross-segment integration. Further, the authors segregated the dynamics of logistics industry in to two parts concentrating on integration role and potential hindrances of 4PL development. Primarily, integration which means merging cross-segment trading partners has to play a role of brokerage agent effectively with appropriate background expertise. However, the transaction cost is applicable in a strategic approach during initial phase and tactical cost on a profit sharing basis. In essence, the 4PL service provider plays a role of logistics consultant. Hobbs (1996) defined transaction costs as cost incurred in an exchange process in the market or transfer of resources between network members. Further, this cost can be classified into information-seeking cost, negotiation and enforcement costs (Tate *et al.*, 2014). In general, the adversarial relationship increases the transaction costs across the SC whereas scope for cost reduction exists through cooperation, teamwork and information sharing among trusted network members (Hobbs, 1996). Secondarily, the hindrances in 4PL development are addressed as aligning technology and organisations for brokerage oriented culture; reaction of manufacturers who have to lose contact with their customers and lack of logistics assets to run the transaction centre where trading partners have to invest on behalf of the buying organisation affecting their working capital and profitability (Fulconis *et al.*, 2007). Therefore, the 4PL transaction centre has to acquire new competencies for evaluation and selection of trading partners in order to carry out cross-segment integration. However, there exists no exclusive 4PL transaction centre model to measure the overall value addition of the network from operation's perspective.

Greenberg *et al.* (2008) identifies three essentials of cross-segment integration namely transaction, platform to control integration activities and different categories of trading partners. In summary, all these essentials of cross-segment integration are executed in the 4PL transaction centre which can combine the competencies of third-parties. However, there is scarcity of quantitative models to manage cross-segment integration even though it is the core of 4PL (Yao, 2010). Hingley *et al.* (2011) put forward the 4PL integration framework to maintain appropriate relationship between trading partners in the transaction centre as shown in fig. 2.5. This is carried out using intensity and complexity of collaborative distribution. The authors suggested transaction oriented 3PL approach for low intensity and low complexity level set up. However, as and when the complexity increases, the integration level can be transformed into relationship oriented 3PL. Similarly, high interaction and low complexity collaborative distribution is sufficed using 4PLs. At last, the high intensity and complexity in the collaborative distribution warrants for specialised platform to act as an integrator known as 4PL transaction centre. In principle, 4PL relationship fits in to customer developer type in the top right quadrant of the matrix. This type of relationship develops over time and trading partners in the network develop in parallel. Besides, this 4PL relationship structure requires greater cooperation and active participation among trading partners and client organisations.

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Figure 2. 5 4PL integration framework

Source: Hingley et al. (2011)

Moreover, trust across the network members can be attained with proper trade-off between adaptation and standardisation (Hingley *et al.*, 2011). Specifically, a service provider should adapt to the client organisation requirements by standardising the process of operations. Therefore, the 4PL transaction centre is deemed as the contact point for controlling the SC. As 4PL provides customised solution, the interdependence between the network organisations is high. In addition, the 4PL transaction centre should specialise in logistics assets and technology to achieve high-end performance (van Hoek and Chong, 2001; Kutlu, 2007). Moreover, communication between trading partners is considered as a driver for combining resources and capabilities to provide effective SC solutions (Svahn and Westerlund, 2007). In addition, sharing information improves visibility in the SC to balance supply and demand (Win, 2008) and enables trust (Kwon and Suh, 2005; Greenberg *et al.*, 2008). Thus, positive relationship exists between trust and commitment (Kwon and Suh, 2005). Forslund and Jonsson (2007) identified lack of available metrics in the literature for cross-segment integration process from operation's perspective.

According to Transaction Cost Economics (TCE), the 4PL transaction centre aims at monitoring and controlling the cross-segment integration process by reducing the operations cost (Hingley *et al.*, 2011). Moreover, integration leads to improvement in material movement, cost savings and information flow in a 4PL setting (Yao, 2010). Specifically, LSPs look for collaborative partnership with customers vertically and other trading partners at the same level horizontally (Schmoltzi and Wallenburg, 2011). Since there is an abundant literature on vertical cooperation, Schmoltzi and Wallenburg (2011) advocated that limited research in horizontal cooperation exists. Cruijssen *et al.* (2007) reported the first survey based findings on opportunities and impediments of horizontal cooperation. Improved productivity, portfolio expansion and reduced cost are reported as the three main parameters which augment horizontal cooperation along with effective resource utilisation, knowledge sharing and access to new business markets. In the next stage, Schmoltzi and Wallenburg (2011) reported that the failure rate of horizontal cooperation is high and ranges between 50 to 70 per cent. This has created keen interest among many researchers to explore the reasons behind it. The authors have reported that there is no exclusive operational model to measure cooperative performance of cross-segment integration. Claro and Claro (2011) found that higher interactions with the trading partners lead to positive relationship for joint investment and collaborative action. The study integrated three perspectives in the form of TCE, relational exchange and network perspective. In general, transaction exchanges are short-term and relational exchange comprises cooperation and joint planning in addition to standard exchange activities. Besides, the coordinator of transaction centre should be aware of network trading partner's perception about the buying organisation. Huo (2012) found that internal integration leads to enhancement of external integration which in turn improves the client organisation's performance.

Figure 2.6 shows the interaction procedure in the 4PL transaction centre to create an equilibrium situation (Antai and Olson, 2013). It is statistically tested that interactions between cross-segment trading partners pooled in the transaction centre escalate themselves from competitive environment to cooperative atmosphere. This envisages stability across logistics assets and resource utilisation by standardising the operations process. In addition, the transaction centre can overcome the resource constraints through mutual learning and partnerships achieving economies of scope on a higher scale. Hence, understanding the client organisation's requirement and satisfying them with potential trading partners is considered as an important criterion to implement and run the 4PL transaction centre. Therefore, a proven model of 4PL transaction centre needs to be formulated and validated through an industry case study.

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Figure 2. 6 Interactions in transaction centre

Source: Antai and Olson (2013)

Besides, the coordinators of transaction centre should spend more time in understanding the functional structure of cross-segment integration by portraying common approach across the value chain. By virtue of the proposed 4PL transaction centre, improvement in the operational efficiency of cross-segment integration and dependence among the trading partners can be monitored effectively due to the standardised process. In order to create a model of 4PL transaction centre, review on existing models is carried out in the next section.

2.4 Review on 4PL Transaction Centre Models

4PL transaction centre must standardise and control the cross-segment integration process with a capability of plug and play solutions (Fulconis *et. al.*, 2007). Moreover, coordination and cooperation capabilities improve the robustness of the 4PL transaction centre between mobilized resources. On the other hand, the researchers called for the quantification of cross-segment integration (Richey *et al.*, 2010) to assimilate the pay-off from the merger. The key areas to integrate are identified as process flow, technologies and merger of cross-segment trading partners (Fabbe-Costes and Jahre, 2007). Furthermore, SC collaboration requires alignment of business with identical strategic focus, standardising the operations process and resource integration to achieve common goal (Naslund and Hulthen, 2012). This can be carried out through systematic and holistic view by jointly delivering the product enabling trust among each other. Similarly, the level of relationship can vary from arm's length to strategic alliance. Arm's length relationship is basically transaction oriented whereas strategic alliance deals with long-term partnership (Vachon *et al.*, 2013). Nonetheless, internal integration can be achieved through information sharing and external integration requires cross-segment trading partners working together for satisfying client organisation. In principle, limited empirical evidence is documented on cross-segment integration and accrued benefits are not reported (Naslund and Hulthen, 2012). The goal of the 4PL transaction centre is to improve the process efficiency and effectiveness across all the trading partners of the network (Win, 2008; Naslund and Hulthen, 2012). Thus, selection of appropriate trading partners is considered as a pre-requisite before conducting cross-segment integration and the same is backed up by Organisation Theory literature (Nielsen, 2003). However, there is no work reported in the 4PL literature for creating a *best of breed* trading partner setup. Zineldin and Bredenlow (2003) reported five dimensions of cross-segment integration capabilities in the form of integration design, coordination, monitoring, governance and transformation, and learning from each other. Integration design deals with selecting right trading partners with *like-minded* approach, coordination refers to standardising the operations processes, monitoring means checking the viability of the integration process, governance deals with holistic approach for achieving common goal and learning mechanism aims to inculcate continuous improvement approach across the 4PL network.

Further, the three levels of logistics alliance capabilities proposed by Zollo and Winter (2002) is reported in fig. 2.7. This framework is explained in three levels known as micro, macro and meta layers. Micro level deals with the operational activities of trading partners like transportation and warehousing. Macro level indicates cross-segment integration design, coordination and collaborative logistics governance along with monitoring the same. Meta level deals with the strategic process for developing research based alliance management. By virtue of these levels, learning is validated by implementing at operational-level implying cyclic process.

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Figure 2. 7 Logistics alliance dynamic capabilities

Source: Zollo and Winter (2002)

Hence, this framework is termed as dynamic due to the continuous improvement and feedback process. This influences frequent interactions between trading partners by creating an inter-organisation learning atmosphere and provides scope to become *best of breed* trading partner in the SC network. Furthermore, 4PL service providers have to manage the above mentioned three layers in their transaction centres effectively. The authors had suggested a need for an analytical framework to develop a transaction centre model which can handle different types of integration relationships. Taking cue from this, an exclusive model of transaction centre for 4PL is developed in this thesis which can integrate the competencies of third parties from operations perspective.

On the contrary, there are issues related to cross-segment integration framework for the development of 4PL transaction centre (Chu *et al.*, 2004). Bourlakis and Bourlakis (2005) proposed a relationship framework to investigate buyer (client organisation) - supplier (service provider) relationship based on logistics asset specificity. The authors demonstrated that 4PL is deemed appropriate whenever the transaction cost between the processes are high. The authors also suggested looking at 4PL services whenever there is high asset specificity and operational complexity. In summary, dual advantages of high asset specificity and low transaction cost is regarded as a source to attain competitive advantage. As a future research, critical success factors to ascertain the potential of 4PL transaction centre are recommended. Thus, standardisation of cross-segment integration enables transparency and improves coordination activities in the 4PL transaction centre. But, exact operating framework to carry out cross-segment integration is not addressed. Simatupang *et al.* (2004) called for synthesising integration performance metrics which verifies contribution to the main goal of the client organisation. The integration metrics should provide performance ratings both at individual and network level. Figure 2.8 depicts the hierarchy of performance metrics in the integration process.

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Figure 2. 8 Integration performance metrics hierarchy

Source: Simatupang et al. (2004)

The hierarchy looks into SC profitability, competitive factors and individual trading partner performance to measure the intensity of integration. SC profitability metrics deal with return on investment, profits and financial statements as an overall performance. The competitive factor metrics such as quality and service level are assessed by comparing with competitors. Finally, performance metrics of individual trading partner are used as an indicator to address their limitations along with supporting metrics as shown in the above figure.

Mukhopadhyay and Setaputra (2006) concluded that the trend of utilising 4PL for cross-segment integration is increasing and suggested developing a dynamic model of transaction centre which considers changes in lagged effect due to time period as a future research. Naesens *et al.* (2007) highlighted scarcity of frameworks in the field of horizontal integration and proposed a framework through resource pooling as shown in fig. 2.9 which yields economies of scale.

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Figure 1.
Decision support framework for horizontal collaboration

Figure 2. 9 Horizontal collaboration framework

Source: Naesens et al. (2007)

The authors called for identifying the goal of cross-segment integration before applying the framework. For instance, reduction of transaction cost can be considered as one such goal. The first level of the framework deals with identifying the strategic fit or *like-mindedness* of trading partners by mapping *AS-IS* to *TO-BE* situation for long-term collaboration. In the second level, allocation of transaction costs and resources are carried out in strategic and tactical situation. This gives a clear spectrum to select the *best of breed* trading partners in 4PL domain. Lastly, the third level focuses on building trust and relationship for various intensity of collaboration. An appropriate feasibility study is proposed to verify the potential of integration using Analytical Hierarchical Process (AHP) by considering 58 parameters. AHP is a MCDM model with a hierarchical framework which downsizes the decision problems in to sub-problems. Consequently, Jharkharia and Shankar (2007) recommended an Analytical Network Process (ANP) framework for selecting LSPs based on four criteria known as Compatibility, Cost, Quality and Reputation. In ANP, preferences among various criteria are performed through pair-wise comparison similar to AHP. Finally, LSP with high suitability index is selected for integration. But, weights derived through pair-wise comparison of the criteria are viewed as subjective and the selected criteria are not considered for the final 4PL vendor selection by the client organisation. Hence, there is a justifiable need to develop quantitative models exclusively for the 4PL transaction centre in order to measure the degree of merger gains.

Fulconis *et al.* (2007) put forward the conceptual transaction centre model for 4PL development by understanding the dynamics of logistics industry. The authors opined that 4PL transaction centre should have the capability to select *best of breed* trading partners and monitor integration between different categories of trading partners. Specifically, the transaction centre shares best practices through learning and improves the capabilities of individual network members (Cruijssen *et al.*, 2007). As 4PL deals with many critical activities, multi-tasking people with expertise need to be selected in order to manage the transaction centre (Fulconis *et al.*, 2007). Figure 2.10 exhibits critical areas of improvement for the transaction centre of 4PL as summarised by the authors. Clearly, 4PL legitimacy is based on the following four factors namely Intermediation, IT, cross-segment integration and value addition. Intermediation deals with merging cross-segment trading partners with minimum transaction cost. This can be achieved through selecting and coordinating *like-minded* trading partners by establishing stability in the 4PL network. On the other hand, IT services for smooth information transaction of the product flow facilitate 4PL service providers to offer customised services to the buying organisation. By virtue of these, value addition to the network is attained through knowledge sharing and benchmarking between the network members. Hence, modelling transaction centre through specialised competencies is considered as vital for 4PL development.

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Figure 2. 10 Key axes of 4PL transaction centre development

Source: Fulconis et al. (2007)

Visser (2007) examined that even though IT contributes to alliance development, scope for further decreasing the merger cost exists in the transaction centre. The author highlights three risk factors associated with the development of 4PL transaction centre in the form of dependence, spill over and conservatism. In summary, working with the different categories of trading partner stimulate ideas from heterogeneous combination of groups leading to innovation in 4PL domain. Thus, the transaction centre of 4PL should comprise research-based innovative models to design and implement comprehensive SC solutions. In principle, 4PL development is dependent on the operations of dynamic transaction centre (Fulconis *et al.*, 2007; Visser, 2007). However, the implementation role of 4PL service providers for cross-segment trading partner integration has scarce support. Moreover, the 4PL transaction centre's strength and value adding capacity are linked to selecting and coordinating the *like-minded* network members (Fulconis *et al.*, 2007). As 4PL works in a dynamic environment, Visser (2007) called for incorporating the time-dependence parameters in modelling the transaction centre. Win (2008) characterises EVA as an appropriate measure to quantify 4PL value addition to the buying organisation. This measure represents current-period objective oriented measure which subtracts the cost of capital from the after-tax profit. The positive number indicates that value is added with the current capital employed for profitability in a given period. As EVA is viewed at company level, it is not regarded as an exclusive SC measure. Thus, measuring 4PL value addition through EVA is not complete as the value contributing attributes may also come from non-financial measures. In view of this, an attempt to measure 4PL value addition from operation's perspective is carried out in this thesis. Thus, synthesising new objective approach is conducted in this thesis for quantifying the 4PL value.

Thakkar *et al.* (2008) proposed an integrated approach which can quantify buyer-supplier relationship from the client organisation's perspective using Interpretive Structural Modeling (ISM) and graph theoretic matrix. Moreover, the buyer-supplier relationship is dependent on the frequency of interactions between the network members. ISM synthesises the logical relationship between dependent and independent variables. Graph theory is helpful for modelling and analysing variety of systems or processes (Grover *et al.* 2004). In principle, ISM provides the visualisation in digraph and graph theoretic approach provides an index for buyer-supplier relationships by pin pointing the reasons for shortcomings. The proposed solution contributed to the theoretical advancement of SCM but the parameters comprise of both subjective and objective measurements. Due to this combinatorial approach, arriving at mathematical equations is complex whenever the number of parameters considered is huge. Leeuw and Fransoo (2009) reported that the cross-segment integration of trading partners is considered as a critical topic in operations management. Nonetheless, the authors found no synchronous view in the literature with regard to cross-segment integration. Anderssen *et al.* (2010) explored that the cross-segment integration is necessary to ensure the existence of 4PL which enables apt coordination and innovation. Cross-segment integration in a SC network should reflect a common focus on the goal as represented in fig. 2.11. Here, interaction enables coordination which in-turn improves the cross-segment integration process.

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Figure 2. 11 Integration, coordination and interaction framework

Source: Anderssen et al. (2010)

Singh (2011) developed an integration framework using six categories of enablers and demonstrated it through a case study using ISM. The six categories include top level management support, organisational factors, information flow, relationship and decision making, mutual understanding and agility. It is found that all the six categories are mutually inter-linked and the top management support is considered as a strong driver to leverage integration. However, ISM is based on expert's intuition and opinion. Hence, validation of the proposed framework through empirical case studies is warranted. In parallel, Yao (2010) put forward the quantitative model for carrying out resource integration in the 4PL framework. The model is developed through Ant Colony Optimisation (ACO) algorithm instead of generally used genetic algorithm (Yao and Liu, 2009) which is complex and difficult to solve multi-attribute optimisation problems. Moreover, ACO algorithm is deemed as the best approach compared to other algorithms for resource integration. ACO algorithm can be explained as an ant travelling in a specific path leaves pheromone to identify the motion path. The greater amount of pheromone helps the ants to select the optimal path in the network. However, ACO algorithms have problems in solving integer programming models as it is considered as single optimisation problem. Further, network capabilities and lower efficiency attained are also considered as drawbacks of the algorithm (Yao and Liu, 2009).

Subsequently, Zhang and Huo (2013) investigated the influence of trust and dependence together for assimilating cross-segment integration in an inter-organisational relationship. Trust can be defined from SCM perspective as keenness to work with a trading partner (Sahay *et al.*, 2003) in order to facilitate cooperation among the network members. Moreover, it reduces opportunism and leverage mutual investments to acquire resources. Dependence is considered as a key enabler to portray trust between the trading partners in SC (McCarter and Northcraft, 2007). The empirical results showed that trust influences cross-segment integration directly. On the other hand, the dependence influences cross-segment integration indirectly through trust. In summary, this situation leads to improvement in financial performance of the buying organisation. The findings from the Zhang and Huo's (2013) study show that the trust acts as a brokerage agent between dependence and cross-segment integration. Antai and Olson (2013) explored scarcity in 4PL models to link theory and actual practice by proposing a transaction centre to capture the interaction between the trading partners. The transaction centre is a hub to carry out dedicated activities of logistics and distribution. The main operations of the transaction centre are reported in fig. 2.12.

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Figure 2. 12 Transaction centre spectrum

Source: Adapted from Antai and Olson (2013)

Figure 2.13 depicts the operating framework of transaction centre (Su *et al.*, 2013) signifying trading partners' roles and responsibilities to promote and envisage innovation or change through frequent interactions.

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Figure 2. 13 4PL transaction centre operations framework
Source: Su et al., 2013

By virtue of mutual partnership and trust across the network members in the transaction centre, an apt environment to promote innovation is possible. This helps the coordinator of transaction centre to understand the requirements of buying organisation and enables effective optimal solution through cross-segment integration. In order to create an interactive and proactive environment in the 4PL domain, an exclusive model of transaction centre is required to integrate all categories of trading partners. Based on the limitations, a dedicated 4PL transaction centre that can deal with a range of cross-segment mergers to provide new capability operating standards is essential. In particular, transaction centre must enable the coordinator to respond for the entire requirements of SC (Visser, 2007). On the other hand, Kutlu (2007) stressed that prior evaluation of the trading partners to escalate them to become *best of breed* is considered as a pre-requisite before developing models. However, a 4PL approach to create a *best of breed* trading partner setup is not addressed in the literature. Thus, an exclusive 4PL performance measurement framework to create a *best of breed* setup for cross-segment integration is warranted as a pre-requisite before modelling the transaction centre. In order to consider appropriate trading partners for 4PL operations, a review of SC performance measures is carried out in the next section.

2.5 Review on SC Performance Measures

As SC is one of the key drivers to achieve competitiveness (Chopra and Meindl, 2007), the organisation's need to adopt appropriate performance measure for their evaluation. In face of never ending SCM growth, selection of appropriate performance measure to evaluate trading partners is a formidable challenge to researchers (Wong and Wong, 2008). Ghalayini and Noble (1996) reported evolution of performance measures in two phases. In the first phase during 1980s, performance measures dealt with only financial indicators. Lack of strategic focus on integration and flexibility issues warranted for quantitative and qualitative performance measures in the SC. Post 1980s to till date constitute the second phase development of performance measure which deals with non-financial measures like enhancing shareholder value and customer satisfaction leveraging holistic perspective. In addition, the main function of performance evaluation is to measure, analyse and improve operations process (Ghalayini and Noble, 1996). Moreover, the performance evaluation technique has to be an inter-related measure envisaging improvement action along with optimal solutions (Cooper *et al.*, 2007; Wong and Wong, 2008). Chen (2009) reported performance measure as "*the process of quantifying the efficiency and effectiveness of action*". In this definition, effectiveness refers to how well the process contributes to the goal and efficiency refers to the amount of resources used in the process. In a similar way, the author defines SC performance measure as "*the process of quantifying effectiveness and efficiency of SC operations*". Therefore, selecting an apt performance measure of SC is considered as vital due to coordination between the inter-organisational activities. However, detailed SC process analysis takes enormous time and resources by getting in to specific details of the activity. In particular, performance measures identify key indicators primarily and further get deep in to the specific activity of the distribution network. Besides, an effective performance evaluation approach enables transparency between the trading partners in a cooperative framework leveraging client organisation improvement (Shafiee *et al.*, 2014).

Gunasekaran *et al.* (2004) called for a balanced approach in SC performance evaluation which can deal with intra to inter-organisation level influencing integrated perspective. In parallel, review on SCM research highlights the transition from exploratory research to mathematical modelling and testing (Sachan and Datta, 2005). Wong and Wong (2008) reviewed the SC performance measures published during 1995–2004. The authors found that performance measures are limited due to the lack of empirical studies in the SC environment. Soni and Kodali (2011) reviewed 619 empirical articles in SCM during 1994 to 2009 by short-listing 21 journals. The authors found that empirical research in SCM is growing at a faster phase. In addition, synthesising new SC performance measures at higher levels are warranted. For example, considering longitudinal data is still at a nascent stage in dynamic SC performance evaluation process (Chen, 2009). Gopal and Thakkar (2012) reviewed the SC performance measures during 2000 to 2011 and reported fewer evidence of structured empirical research. Bennett and Klug (2012) further warranted for the development of effective SC performance measures to achieve competitiveness in the current business environment. Since, performance measures differ for every specific field leading to uni-dimensional measures; similar procedure cannot be used to evaluate SCs as it deals with multi-dimensional measures. In particular, uni-dimensional measures deal with intra-organisation level which is inflexible and lacks strategic focus towards SCI (Chopra and Meindl, 2007). This resulted in the development of mathematical modelling and case study approach for evaluating SCs which provides clearer representation of the framework (Sachan and Datta, 2005; Wong and Wong, 2008). Specifically, Wong and Wong (2008) and Soni and Kodali (2011) collectively highlighted scarcity in models which can objectively aggregate individual performance measures into a single overall performance index. Besides, this type of an integrated measure helps the coordinators to assimilate improvements in their SC under different scenarios for joint decision making (Shafiee *et al.*, 2014). Therefore, DEA methodology is viewed and recommended as an appropriate performance evaluation technique for SCs (Wong and Wong, 2008; Soni and Kodali 2011). In fact, this technique is developed by Charnes *et al.* (1978) and extended by Banker *et al.* (1984) to arrive at relative efficiency for the given data through efficient frontier concept. In the next section, critique on how DEA differs from other SC performance measures is reported.

The comparative study between DEA and other SC performance measures is carried out by highlighting the problems with current methods with respect to parametric and non-parametric approaches. Parametric approaches deal with gap analysis in performance measurement and it is highly graphical in nature. For instance, spider diagram and Z-chart integrates all the parameters for evaluation but fails to synchronise multiple performance scores into a single index. In addition, the financial ratio analysis is applied to calculate relative efficiency based on the given inputs and outputs. However, different ratios interpret diverse implications and combining various ratios in to a single performance index is difficult. Moreover, it causes inconvenience to the SC coordinator for integrating multiple performance scores into a single index. But, DEA technique can analyse multiple input and output parameters simultaneously to arrive at a single overall performance index (Charnes *et al.*, 1978; Cooper *et al.*, 2007) through linear programming approach (Abri, 2012) which is gaining strategic importance in decision analysis. Multiple regression statistical method is looked to determine the relationship between the dependent and independent parameters for performance evaluation. Even though strong theoretical foundation exists, this technique can analyse one dependent parameter at once and reflects average value among its peers which neither serves as a benchmark nor exists in the actual scenario. Nonetheless, the regression analysis has to be repeated as and when multiple outputs (dependent parameters) are added. Conversely, DEA can deal with complex relationships without any prior trade-off assumptions between the dependent and the independent parameters simultaneously. Also, this technique signifies the suggestive improvement guidelines for individual trading partner by relatively comparing with the *best-peer* network member under study. Moving forward, non-parametric method like Balanced Score Card (BSC) which translates strategic objectives into coherent set of performance measures is considered (Kaplan and Norton, 2004). BSC links the key factors such as customer, product, market development and process. But, this technique fails to quantify mathematical-logical relationship even though enormous studies are conducted in SC domain (Shafiee *et al.*, 2014). In addition, arriving at single efficiency score is not possible with BSC unlike DEA which deals with cross-functional measures effortlessly. On the contrary, the various performance measure approaches are reported in the form of questionnaire and measurement system design (Dixon *et al.*, 1990). Nonetheless, outcomes of these measures cannot be used by the SC coordinator for joint decision making as influenced in DEA. Lin *et al.* (2012) looked into simulation approach as an appropriate SC performance measure which can capture complex relationships with various trading partners. This process is also called as simulation optimisation which identifies a set of feasible solutions for a particular process. However, building a simulation model is time consuming where prior history of the trading partners performance must be available. Moreover, satisfying multi-objective optimisation problem effectively is an issue with simulation models warranting for amalgamation with other performance measures. Therefore, DEA is deemed as an appropriate technique for carrying out decision analysis under MCDM environment by enhancing the capabilities of trading partners in the long-term (Cooper *et al.*, 2007).

In the next stage, Vaidya and Hudnurkar (2013) proposed a MCDM approach for SC performance evaluation for enhanced scientific validity. AHP methodology, which uses weighted score obtained through pair-wise comparison of criteria, is considered appropriate to arrive at a single performance index. Nonetheless, pre-determined weights obtained through experts are considered subjective in nature and the model faces rank reversal issues (Naesens *et al.*, 2007). Moreover, the various criteria considered in AHP technique are independent of each other. In order to overcome this issue, ANP is looked for performance evaluation. But, this technique cannot make an impact until a secondary level of sub-criteria is defined to arrive at the final solution (Jharkharia and Shankar, 2007). On the other hand, DEA deals with variable weight scheme wherein the relative weights of individual trading partner are derived from the data unlike fixed weight scheme. Thus, DEA is considered as an objective approach. Further, fuzzy models are considered which can combine both the qualitative and quantitative measures without making trade-off. As fuzzy models are dependent on experts or practicing manager intuitions and opinion, this method may portray bias in the evaluation process and is viewed as subjective in nature (Bayrak *et al.*, 2007). Consequently, Buyukozkan *et al.*, (2008) proposed fuzzy-AHP and fuzzy-Technique for Order Preference by Similarity to Ideal Solution methods in order to involve group decision makers for SC evaluation. Even though bias can be minimised through joint decision making environment, the approach is considered as subjective in nature. Moreover, the quantifiable improvement targets need to be specified along with evaluating trading partners in an integrated perspective for the SC network (Shafiee *et al.*, 2014). In order to overcome these issues, DEA is deemed as an appropriate performance measure for evaluating SCs in the dynamic business environment (Wong and Wong, 2008; Chen, 2009). In the next section, rationale for DEA approach is put forward.

2.5.1 Rationale for DEA Approach

The non-parametric DEA technique is widely adopted in SCM literature for performance evaluation capturing multi-dimensionality (Abri *et al.*, 2009; Wong and Wong, 2008). In DEA, the entity under study is known as Decision Making Unit (DMU) which comprises multiple inputs to produce multiple outputs. This technique is considered as robust, standardised and transparent methodology which derives optimal weights from the data (Cooper *et al.*, 2007). These derived weights can also be used as an improvement direction for DMU under study. In general, DEA efficiency score of one represents maximum attainable efficiency. In addition, flexibility of this technique to adapt with different type of DMU structure makes it a competitive performance measure (Cooper *et al.*, 2007). In general, DEA looks at minimising the inputs and maximising the outputs (Cook *et al.*, 2014). Weber (1996), Braglia and Petroni (2000) and Min and Joo (2009) collectively reported the application of DEA in SC environment. Cooper *et al.* (2006 and 2007) further demonstrated application of DEA with diverse context in different countries for performance evaluation. The authors stressed that DEA technique has opened opportunities to solve cases which are resistant to other techniques due to their complex relationships between multiple inputs and outputs. Some examples include evaluation of England and Wales police forces, maintenance activities of U.S. Air Force bases at different locations. Besides, this approach is vastly considered as one of the apt benchmarking techniques for comparing banks and site evaluations depicting empirical standards of excellence. In addition, this technique puts forward new insights on performance evaluation by identifying sources of inefficiencies in individual DMUs. Chen (2009) supported that DEA score portrays diverse applications where in the relative efficiency frontier is used to compare peer DMUs in the SC. Apart from supporting production model, this technique is well connected with statistical methodologies which are extensively discussed in literature. Thus, DEA enable managers to estimate relative efficiency for individual trading partners and perform diverse decision analysis under MCDM framework (Weber, 1996). Moreover, this approach simplifies decision making since the relationship between input-output parameters is deduced from the data and need not be specified in prior. In principle, DEA approach identifies the efficiency frontier with best values from the dataset and compares peer members relative to the enveloped frontier. Therefore, the key advantage of DEA technique over other performance measures is that it can deduce input-output parameter weights objectively from the empirical data along with reference sets. Nonetheless, these reference sets show improvement direction to inefficient DMUs in order to determine the realistic targets for reaching efficiency frontier (Jalalvand *et al.*, 2011). By virtue of this procedure, subjectivity in the evaluation process is completely eliminated. As this research study focuses on operations perspective, DEA technique is justified as an appropriate objective measure for performance evaluation.

2.5.2 Limitations of DEA Approach

Though DEA is recommended as an appropriate SC performance measure, Chen (2009) looked in to its limitations. Firstly, the input and output data must be available to perform analysis in order to interpret meaningful results. But, practically some data might be confidential and may not be available. Secondly, the number of DMUs must be larger than the number of input–output parameters to satisfy degrees of freedom condition. This type of necessary and sufficient conditions may not be prevalent in the real world scenario. Thirdly, this technique must be applied to homogeneous DMUs having same strategic goal and vision. Nevertheless, SCs have many tiers with different objectives for individual trading partners. Fourthly, classical DEA models do not consider lagged effect under dynamic (time dependent) scenarios for calculating the relative efficiency. However SC works in a dynamic environment, thus, implying fundamental difference in the performance evaluation process. In order to overcome the above mentioned limitation, extensions to the traditional model is warranted to correlate with the practical scenario by combining DEA with multi-disciplinary approaches like statistics and simulation. Hence, the existing DEA model with modifications is regarded as an appropriate performance measure for comprehensively evaluating the SCs (Chen 2009; Wong and Wong 2008). However, the DEA performance measure does not consider all possible situations in the evaluation process due to its own limitations. Even though significant portion of the network is automated, organisations fail to achieve competitive advantage (Sahay and Ranjan, 2008). In order to achieve completeness in the evaluation process, Sahay and Ranjan (2008) and Vaidya and Hudnurkar (2013) called for combining SC performance measure with business analytics. Schlafke (2013) defined business analytics as an emerging domain which can facilitate decision making process by understanding the dynamics of the process. This includes statistics, econometrics and mathematics for data collection and analysis.

2.5.3 Need to Integrate DEA with Analytics

Recently, studies have shown negative effects in SC relationships with respect to trust and cooperation (Vaidya and Hudnurkar, 2013). As the aspects like trust and cooperation can not be quantified, Sahay and Ranjan (2008) addressed the need for real time Business Intelligence (BI) in SC environment. BI concept integrates and consolidates past operations data to support organisations for decision making process. Moreover, BI includes knowledge management, Enterprise Resource Planning (ERP) and data mining techniques to draw inferences from the broader perspective (Beckett *et al.*, 2000). Besides, BI deals with arriving at appropriate relationship between dependent and independent variables. In general, this technique is also called as business analytics to facilitate real-time decision making process (Sahay and Ranjan, 2008). In addition, the analytics provide decision maker better insights about an issue from the operational data stored in the transaction system. Furthermore, a wide adaptation of analytics in customer relationship management and SCM software has allowed organisations to integrate their demand and supply chain. Hence, SC analytics is recommended to improve the decision making process that impacts the bottom line and adds value to the organisation. In particular, SC analytics is used to extract and leverage meaningful inferences for the coordinator through enormous amount of past data (Schlafke, 2013). This processes real-time heterogeneous information and percolates down in to clusters of focused view of business. For example, concepts such as active warehousing and real-time analytics have taken a limelight in the field of SCM (Sahay and Ranjan, 2008). In principle, the primary goal of real time BI is to merge analytics with modelling approaches in order to facilitate decision makers to take actions proactively (Lee and Johnson, 2014). Thus, enabling analytics with the mathematical modelling approach is considered holistically to achieve the competitive advantage. As SCs have multiple trading partners with different priorities and size, application of analytics can help the decision maker to segregate the trading partners into *like-minded* group. In the next section, summary of literature review on 4PL transaction centre and SC performance measure is presented.

2.6 Summary of Literature Review

Based on the above discussions, summary of literature review with respect to 4PL transaction centre and SC performance measure are reported as follows:

1. In the current scenario, organisations are also focusing on non-core competencies for further improvements. This has resulted in the emergence of logistics and SCM concept. In particular, co-operation among trading partners belonging to the same SC is recognised as a powerful source of competitive advantage
2. Logistics industry is undergoing transition to brokerage oriented approach. Further, logistics innovation has become a vital element for large enterprises to improve global competitiveness
3. 3PLs are positive in maintaining the relationship with client organisation but lacks SC integration capabilities, thus, creating a vacuum. This has led to the emergence of 4PL which can manage the entire SC based on client organisation's requirement
4. 4PL is viewed as the next generation logistics which aims at enhancing value proposition. Synthesising new objective approaches for measuring value addition is warranted
5. 4PL is considered appropriate whenever there is high asset specificity and operational complexity. Dual advantages of high asset specificity and low transaction cost is viewed as a source of attaining competitive advantage. In summary, 4PLs can provide broad industry standards for trading partners requiring similar service to achieve economies of scale
6. Technological and organisational uniqueness, reaction of manufacturers and lack of logistics assets are identified as the critical hindrance factors for 4PL development. In parallel, three propositions for 4PL development are put forward viz. ability to provide globalised solutions, standardisation and control of integration process, and information sharing to develop synergies
7. In order to coordinate between various categories of trading partners, the 4PL acts like an intermediary creating a common platform in the distribution network. This platform which acts like a SC control room is known as the transaction centre
8. The transaction centre of 4PL has to acquire new competencies for evaluation and integration of trading partners in order to become a single point integrator. Besides, the transaction cost is applicable in a strategic approach during the initial phase and subsequently the tactical cost on a profit sharing basis

9. 4PL transaction centre should have the capability to select *best of breed* trading partners and monitor cross-segment integration to provide comprehensive SC solutions. In particular, cross-segment integration comprises of different categories of independent trading partners coming together to align the SC
10. The main goal of the 4PL transaction centre is to improve process efficiency and effectiveness of the SC network. Besides, the top management support is considered as a strong driver to leverage integration
11. Transaction centre must enable the coordinator to respond for the entire requirements of SC by providing a plug and play solutions. Specifically, 4PL transaction centre creates a platform to share best practices between cross-segment trading partners through mutual learning and improves the capabilities of individual trading partners
12. The 4PL transaction centre should comprise of research based innovative models to design and implement comprehensive SC solutions
13. Selection of the appropriate performance measure to evaluate trading partners is a challenge to researchers and viewed as critical in SC literature. The performance evaluation technique has to be an inter-related measure envisaging improvement action along with optimal solutions
14. Performance measures are limited due to the lack of empirical studies in SC environment. In addition, synthesising new SC performance measures at higher levels are warranted which can aggregate individual performance scores into a single overall performance index
15. As performance measures differ for every specific field, development of mathematical modelling and case study approach for evaluating SCs is deemed appropriate. Moreover, DEA methodology with modifications is recommended as an appropriate performance measure for SCs
16. Motivation to apply DEA in SC environment includes ability to process multiple inputs-outputs; assumption and relationship between the input-output parameters need not be specified; highlighting information of both in-efficient and efficient trading partners. Also, flexibility of this technique to adapt with different types of network members makes it a competitive performance measure

17. BI concept integrates and consolidates information to support organisations for decision making process by analysing past operations data. Moreover, BI includes knowledge management, ERP and data mining techniques to draw inferences from the broader perspective. The primary goal of real time BI is to merge analytics with mathematical modelling approaches in order to facilitate SC coordinators for making effective decisions

From the above observations, the major and specific gaps in the literature are organised as follows:

1. In order to create an interactive and proactive environment in the 4PL domain, an exclusive transaction centre is required to integrate different category of trading partners. However, limited theoretical frameworks and empirical study exists on the transaction centre model even though it is the core of 4PL
2. 4PL transaction centre presents additional challenges in the form of implementation characteristics and monitoring cross-segment integration. Nevertheless, no synchronous view with regard to cross-segment integration of trading partners is reported in the 4PL literature
3. 4PL development is dependent on the operations of dynamic transaction centre working towards a common goal. However, the role of 4PL service providers to implement transaction centre is not well explored
4. A transaction centre model is necessary to facilitate the client organisation and the 4PL service provider for resource analysis and measuring its impact on the operational performance. Nonetheless, there is no exclusive transaction centre model of 4PL from operations perspective
5. The 4PL conceptual model identifies EVA as an appropriate measure of value creation to the buying organisation. But, EVA has little engineering meaning. Moreover, this measure is considered at company level but cannot be considered as an exclusive 4PL SC measure
6. Selection of *best of breed* trading partners is considered as a pre-requisite before conducting integration in the 4PL transaction centre and the same is backed up by

Organisation Theory literature. However, there is no work reported in the 4PL literature for creating a *best of breed* trading partner setup

7. DEA approach is deemed appropriate for evaluating SCs which considers homogeneous trading partners with same goal and vision for performance evaluation. But in a practical scenario, this type of setup in a distribution network is not prevalent
8. Performance evaluation of trading partners using traditional DEA models is carried out based on the collected data implying static consideration. Nonetheless, SC works in a dynamic environment. Thus, leading to bias in an evaluation process

Despite this work, there exists no available transaction centre model that can deal with a range of trading partner integration to support 4PL operations. To put it succinctly, the 4PL transaction centre plays a decisive role to provide comprehensive SC solutions. One can conclude that, there is no research study carried out on modelling the 4PL transaction centre. Study presented in this thesis is a first attempt in developing a mathematical model by integrating the concepts of 4PL transaction centre and DEA technique. The original contribution in this thesis is to synthesise an exclusive 4PL approach to evaluate trading partners and comprehensively integrate the improved competencies of trading partners for sustaining the post-merger effects in a dynamic transaction centre. Therefore, the eventual outcome of this study deals with modelling a 4PL transaction centre that provides the capability of new operating standards. In the next chapter, methods and methodologies for modelling the 4PL transaction centre are reported along with rationale for selecting the case study company to validate the research aim.

CHAPTER 3: METHODOLOGY

3.1 Introduction

Based on critique of the literature, 4PL service provider requires deep understanding of the transaction centre before conducting cross-segment integration. For this reason, it is emphasised that both the LSPs and client organisation must invest time and money for mutual understanding before getting into a 4PL framework. In parallel, the coordinator should possess pre-requisite multi-criteria skills with advanced optimisation competencies to manage the 4PL transaction centre. Therefore, the primary role of a transaction centre coordinator is to ensure transparency and coordination between the network members of SC. In continuation, consistency of the cross-segment integration is linked to the anticipated risks and dependence among trading partners. Taking cue from this, a procedure to synthesise transaction centre for carrying out cross-segment integration is considered necessary to enable smooth functioning of the 4PL service provider. The research study presented in this thesis is an attempt to model the transaction centre considering performance and cost perspective. In particular, the proposed transaction centre model performs two critical roles in the 4PL framework. The first critical role looks at evaluation of the different categories of trading partners along with providing suggestive guidance for improvement in order to create a *best of breed* 4PL setup. Based on the evaluation outputs, standardisation of cross-segment integration in the transaction centre is attained as a part of second role. From the literature review and observations made, aim of the research work is achieved with the following methods and methodologies addressed in this chapter. In the next section, a brief introduction to DEA operating framework and rationale for the dynamic performance evaluation is addressed.

3.2 DEA Operating Framework and Justification for Dynamic Evaluation

Ever changing business conditions have made buying organisations look for effective SC performance measures which includes efficiency output and resource details (Chen, 2009). In parallel, SC research supported DEA approach as an appropriate performance measure for productivity measurement (Shafiee *et al.*, 2014). An attempt to clearly understand the inherent features of DEA is carried out in order to monitor the actual performance status along the SC. Advantages like ease of use, implying resource usage along with improvement directions, combining quantitative and qualitative data have motivated to apply DEA approach (Cooper *et al.*, 2007) in this thesis. Besides, the DMU under study is designated with a suffix 'o'. Figure 3.1 illustrates the analogy of DEA principle for comparing eight stores (A to H) with homogeneous inputs to produce similar outputs. The X-axis has the number of employees in the store and the Y-axis has the sales generated in USD represented in lakhs. Here, slope of the line B is identified as the frontier and remaining stores (DMUs) can be relatively compared with reference to this frontier.

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Figure 3. 1 DEA principle for store comparison

Source: Cooper et al. (2006)

Figure 3.2 shows the comparison between regression analysis and DEA approach. Here, least square method considers average values to fit the regression line while DEA uses the frontier line from origin. Further, the inefficient DMUs can be made efficient through projection mechanism. For example, DMU A in fig. 3.1 can become efficient either by reducing its input from two sales people to one or by increasing its output from USD one lakh to two lakhs. This approach can also be utilised as a benchmarking tool since it selects best value in the dataset and signifies improvement direction in the form of projections for peer DMUs. Moreover, a group of feasible DMUs in DEA is regarded as production possibility set *P* which comprises multiple inputs to produce multiple outputs (Davoodi and Rezai, 2014).

Stemming from conventional Operations Research (OR) concepts, DEA can also be represented using Linear Programming Problem (LPP) which is backed up by the vast body of knowledge.

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Figure 3. 2 DEA and Regression analysis store comparison

Source: Cooper et al. (2006)

One more reason to apply DEA for modelling the 4PL transaction centre corresponds to input or output orientation. Depending on the situation, suitable orientation can be used by the coordinator for managing 4PL operations. For instance, input oriented DEA model deals with minimising inputs to attain the given outputs and output oriented DEA model covenant with maximising outputs from the given inputs (Cooper *et al.*, 2007). In addition, the input-output DEA orientation is also called as "*minimal and maximum principle of productivity*" (Shafiee *et al.*, 2014) respectively. Mathematically, DEA principle is based on the radial efficiency θ formula as shown in equation (3.1).

$$\theta = \frac{Output}{Input} \qquad \text{……………………. (3.1)}$$

Further, DEA uses variable input v_i and output u_r weights which can be derived from the data objectively for n DMUs. As reported by Cooper *et al.* (2007) sum of inputs (X) and outputs (Y) of a DMU can be depicted in equation (3.2) following θ principle.

$$\frac{\sum_{r=1}^{n} u_r Y}{\sum_{i=1}^{n} v_i X} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

The above ratio can be maximised to find u_r and v_i using LPP technique after converting the fractional problem into linear program. This forms the analogy for basic DEA formulation known as Charnes, Cooper and Rhodes (CCR) model which can be represented as follows:

$$\begin{gathered} \text{Maximise} \quad u_r y_o \\ \text{subject to constraints} \\ v_i x_o = 1 \\ -v_i \boldsymbol{X} + u_r \boldsymbol{Y} \leq 0 \\ \text{where } v_i \geq 0 \text{ and } u_r \geq 0 \end{gathered} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

Liu *et al.* (2012) conducted a citation based review of DEA literature from 1978 to 2010 and found that the CCR model is deemed as a core model for performance evaluation process. In order to overcome degrees of freedom issues in DEA, the number of DMUs n has to be greater than or equal to the maximum of (m*s) or (3*(m+s)), where m refers to number of inputs and s denotes number of outputs. Mathematically, this can be represented as follows:

$$n \geq \max. \{ (m*s), (3*(m+s)) \} \qquad \ldots\ldots\ldots\ldots\ldots\ldots.. (3.4)$$

But, Cook *et al.* (2014) argue that the above mentioned condition is considered to ensure better discrimination effect between DMUs even though it is not imperative. Duality of LPP is adopted in the study to counter shortcomings from the primal form (Charnes *et al.*, 1978; Tajbakhsh and Hassini, 2014). In particular, max-slack solutions through input excesses and output shortfalls can be attained along with significant reduction in the computational effort. The purpose of applying DEA in this thesis is further characterised with respect to Returns To Scale (RTS) which can be either constant ‘c-RTS’ or variable ‘v-RTS’. Here, c-RTS corresponds to CCR model and v-RTS relates to Banker, Charnes and Cooper (BCC) model as shown in fig. 3.3.

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Figure 3. 3 RTS characterisation in DEA

Source: Cooper et al. (2006)

RTS deals with the proportional relationship with inputs and outputs which provides critical information of improvement direction to the trading partners for reaching the efficiency frontier (Abri, 2012). Besides, CCR and BCC model is mainly differentiated with respect to RTS characterisation. BCC model can be mathematically represented like CCR model with the addition of a convexity constraint as shown in equation (3.5); where ***e*** is considered as row vector with all elements unity and $\boldsymbol{\mu}$ is viewed as column vector of inputs and outputs.

$$\boldsymbol{e\mu} = 1 \qquad \text{…..………………} \ (3.5)$$

As 4PL activity deals with strategic (long-term) and tactical (mid-term) issues, RTS characterisation merges well with the requirements of proposed model. By virtue of DEA, the long-term arrangements for integrating cross-segment trading partners along with mid-term performance evaluation of the network members are presented to support 4PL transaction centre operations. In addition, CCR efficiency score is termed as Technical Efficiency (TE) and BCC efficiency score is regarded as Pure Technical Efficiency (PTE). Alternatively, the optimal efficiency score θ^* under c-RTS is considered as global TE interpreted as θ^*_{CCR}. Contrarily, θ^* under v-RTS is regarded as local TE represented as θ^*_{BCC}. In general, TE looks for maximising outputs from the given inputs (Ahn and Min, 2014). Thus, the optimal input oriented efficiency

θ^* score is related to TE. Further, the optimal output oriented efficiency score η^* and θ^* are related as follows:

$$\eta^* = \frac{1}{\theta^*} \qquad \text{………………..} \ (3.6)$$

However, efficient trading partner under both RTS characterisations is viewed as operating under most productive scale size. For instance, if a DMU has full $\theta^*{}_{BCC}$ score but low $\theta^*{}_{CCR}$ score; then the trading partner is regarded as operating locally efficient and globally inefficient due to the scale size. In addition, Scale Efficiency (SE) is calculated as the ratio of TE to PTE. Here, TE means CCR score which prevails only c-RTS (radial reduction and expansion) leading to global technical efficiency. PTE refers to BCC score which has v-RTS (convexity condition) leading to local technical efficiency. Based on the efficiency scores under both characterisations, SE can be mathematically depicted as follows:

$$SE = \frac{\theta^*{}_{CCR}}{\theta^*{}_{BCC}} \qquad \text{…………………..} \ (3.7)$$

To decompose the efficiency, equation (3.7) is re-organised as shown in equation (3.8). In summary, this decomposition depicts the sources of inefficiency due to *inefficient operations* (PTE) or *disadvantageous working condition* (TE) due to scale size; or by both.

$$\text{TE = PTE * SE} \qquad \text{..…………………. (3.8)}$$

By virtue of this decomposition, individual trading partner can work on their limitations to reach the efficiency frontier in order to accomplish SE. Moreover, SE reflects the ability of the trading partner to achieve an optimal size through productivity improvement (Ahn and Min, 2014). In general, network members in the SC might have advantages either in terms of technology or cost (Cooper *et al.*, 2007; Ray and Ray, 2014). In such cases, Overall Efficiency (OE) considers TE and cost efficiency simultaneously to achieve completeness in the evaluation process.

Nonetheless, the cost related efficiency is termed as Allocative Efficiency (AE). Mathematically, OE can be represented as follows:

$$OE = AE * TE \qquad \text{...………............ (3.9)}$$

Conversely, the contemporary literature in DEA called for multi-stage performance evaluation in the SC network (Matin and Azizi, 2014). In this type of network structure, output of a particular stage may be considered as inputs for the next subsequent stage (Davoodi and Rezai, 2014; Matin and Azizi, 2014). Moreover, these types of multi-stage DEA models are classified into closed or open systems as shown in fig. 3.4.

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Figure 3. 4 Multi-stage DEA evaluation systems

Source: Davoodi and Rezai (2014)

In the closed DEA system model, the intermediate outputs are not changed unlike in open DEA system model. Similarly, various DEA models are developed from the application perspective to address specific issues in the modelling process and the attained DEA results are compatible with different knowledge domains. For instance, super efficiency DEA model is applied to address the tie-situation in efficient DMU rankings. In this model, the efficiency scores are obtained by eliminating the data of DMU under study from the solution set of constraint in the LPP. During verification and validation phase of the model development, comparison of DEA efficiency scores between dissimilar systems needs to be carried out. In such cases, the system efficiency DEA model can be applied which ignores the convexity condition in the P. Specifically, this method eliminates inefficiency condition in individual system through the projection mechanism before comparing the efficiency frontiers. Conversely, sharper discrimination between the datasets can also be obtained through bi-lateral DEA comparison. In summary, system efficiency and bi-lateral DEA models can be used to compare the significant shift in efficiency frontiers between the independent groups (Cooper *et al.*, 2007). Further, the difference between these groups can be statistically validated. For this reason, non-parametric Wilcoxon-Mann-Whitney rank sum test (Aczel and Sounderpandian, 2008; Amado *et al.*, 2013) can be adopted as the theoretical distribution of DEA efficiency scores is generally not known. However, the detailed discussions on these models are reported in chapters-4 and 5 respectively.

3.2.1 Justification for Dynamic DEA Evaluation

As the transaction centre of 4PL works in a dynamic (time-dependent) environment, modifications and extensions to the conventional DEA model are considered as the way forward in SC research (Seydel, 2006). In practice, the trading partners in the distribution network with autonomous or semi-autonomous decision making capabilities have dynamic impact on their performance as well as subsequent chain partner's performance (Chen, 2009). Thus, the methodical and efficient ways of evaluating performance in the SC environment is necessary to develop research based innovative models. The growing complexity of the distribution network has made time dynamics an influential factor in the modelling approach (Chen, 2009; Visser, 2007; Mukhopadhyay and Setaputra, 2006). Dynamic DEA models calculate the relative efficiency by considering inter-relationship between DMUs in multiple periods (Kao, 2013). Recent work by Chen (2009) looks at dynamic effects in the SC network by merging DEA with other methodologies. Further, incorporating lag parameters with respect to time eliminates bias in the evaluation process (Chen, 2009; Gujarati and Sangeetha, 2007) and helps the decision maker to capture real life situation in the distribution network. In economics, the lapse in time response between dependent and independent parameters is termed as lag (Gujarati and Sangeetha, 2007). Moreover, dynamic evaluation is considered important but often an ignored property in SC performance (DEA-Solver-Pro, 2009; Davoodi and Rezai, 2014). To precisely measure performance of chain partners, Chen (2009) stressed on incorporating dynamic effects between multiple inputs-outputs for DEA evaluation. Though traditional DEA models deal with static inputs-outputs, this can lead to errors in the modelling approach. Further, policy decisions taken by individual trading partners can have a dynamic impact on their own performance as well as others. Besides, the investments in production facilities, IT and impact of securing environment initiative can be realised over time. Hence, interactions in the network of trading partners can create a ripple effect with respect to time (Chen, 2009). Thus, dynamic evaluation is considered in this thesis leveraging better discrimination between the trading partners. In addition, merging DEA with other methodologies for risk and uncertain environment is demonstrated for the SC process design (Chen, 2009). For instance, succinct synopsis by Watson *et al.* (2011) illustrates dynamic DEA evaluation to morning star ratings for Australian equity firms considering panel data from 1990 to 2005 by providing stochastic properties of efficiency measure. Besides, DEA has several models which evaluate the relative efficiency with respect to time like window analysis and malmquist index. Here, window analysis optimises the single time frame by dividing in to multiple periods (Cooper *et al.*, 2007; Kao, 2013) and malmquist index estimates the productivity changes of a DMU at two different time periods which can be represented as the product of frontier shift and catch-up effect (Ahn and Min, 2014). Nonetheless, these models neglect inter-temporal effects (see fig. 3.5) between input-output parameters and focuses on independent period t (DEA-Solver-Pro 2009).

Figure 3.5 represents the working mechanism of a dynamic model for the given inputs and outputs during the period 't' and '$t+1$'. The performance evaluation process comprises carry-over effect from period 't' in the form of lag to the period '$t+1$' apart from regular inputs and outputs. In particular, this type of lagged effect is termed as inter-temporal effect between inputs and outputs (DEA-Solver-Pro, 2009). For instance, if a person receives a permanent annual increment of USD 2000; the expenditure pattern of the person increases year on year which is termed as distributed lag patterns (Gujarati and Sangeetha, 2007). By virtue of this mechanism, Chen (2009) demonstrated the application of dynamic effects on multiple inputs-outputs by adding lag parameters with the time trajectory.

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Figure 3. 5 Dynamic model with inter-temporal effect

Source: DEA-Solver-Pro (2009)

The author further reported that the application of static DEA evaluation in a dynamic environment can lead to efficiency score changes and rank reversals. However, Chen's (2009) dynamic DEA model assumes positive impact of lag parameters on the subsequent chain partner. In this thesis, the dynamic evaluation model is extended through the relaxation of output disposability function of lag parameters for individual trading partners which can have positive, neutral or negative effect. This approach contributes to the theoretical advancement in dynamic DEA evaluation and makes the modelling approach realistic to the industry scenario. As a result, incorporating dynamic DEA evaluation with variable lag effect provides accurate performance over time. In the next section, methods and methodology to achieve the research aim is reported.

3.3 Methods and Methodology

Initially, literature review on "*difference between 3PL and 4PL operations process, 4PL roles and responsibilities, hindrance factors for 4PL transaction centre development and allied risk categories*" is carried out by referring journals, books, conference papers and related documents. In parallel, brainstorming on implementation of 4PL transaction centre and challenges of cross-segment integration are discussed with the industry personnel from practical point of view (see fig. 3.6). Based on the literature review and brainstorming outcomes, transaction centre that can provide new capabilities for 4PL operations is modelled in this thesis.

In particular, development of novel approaches related to evaluation and integration process are addressed to comprehensively combine the competencies of third parties.

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Figure 3. 6 Brainstorming 4PL operational challenges with industry personnel

Figure 3.7 shows the solution procedure adopted in this thesis.

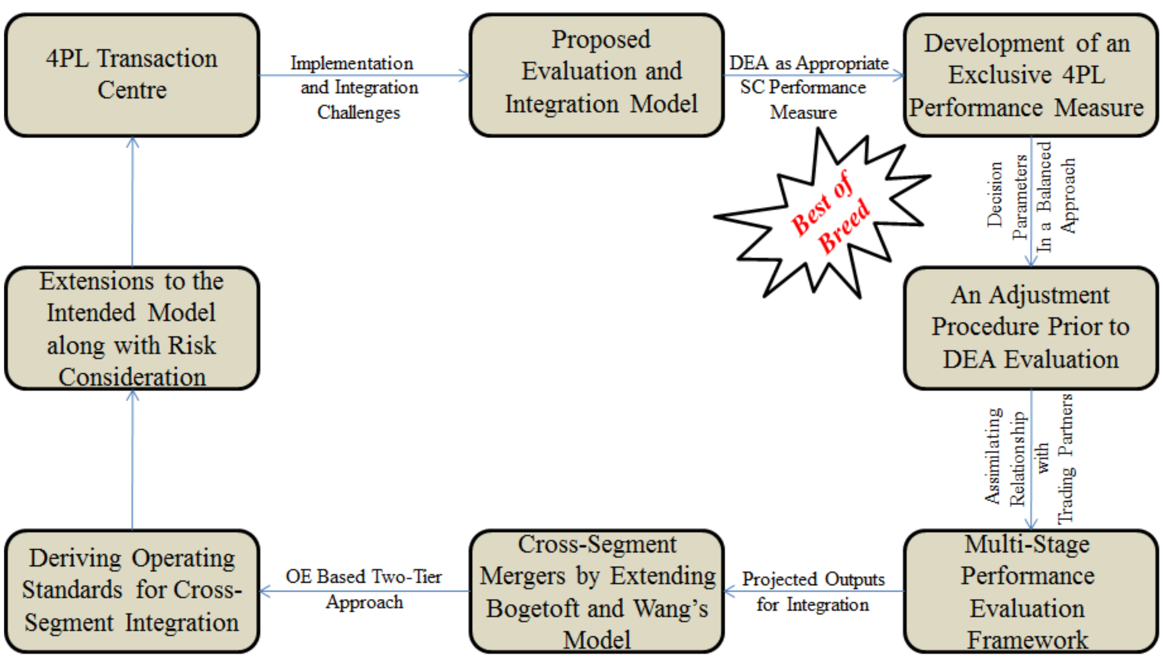

Figure 3. 7 Solution procedure to model 4PL transaction centre

Consequently, review of existing approaches for evaluating SC performance are assimilated with regard to parametric and non-parametric methods highlighting major merits and de-merits in order to validate DEA approach as an appropriate performance measure. In order to get acclimatised with the mathematical modelling environment, training and familiarisation in DEA-Solver, Minitab 14 and E-Views 5 software is executed to develop the transaction centre. The initial phase of model development is carried out through interactions with the industry personnel to understand their SC process and scope of the study is defined from operations perspective.

Hammervoll and Toften (2010) called for synthesising SC performance measures considering both the trading partners and buying organisation perspectives. Therefore, the proposed 4PL performance measurement framework to create a *best of breed* trading partner setup for the transaction centre is carried out in two parts. Initially, a pre-requisite approach to cluster heterogeneous trading partners into *like-minded* group for further DEA evaluation is proposed from the trading partner perspective. Subsequently, a multi-stage performance evaluation DEA framework is synthesised from buying organisation perspective. Specifically, interaction based and transaction specific decision parameters are considered in a balanced approach. Besides, the decision parameters data are collected for the selected trading partners (suppliers and LSPs) of the case study company through Request For Information (RFI) and the secondary data from IC-Soft ERP software. In summary, the decision parameters for developing an exclusive 4PL performance measurement framework are reported through exhaustive literature review in this thesis. Nonetheless, the summarised criteria may be added or deleted depending on the scope of the SC (Kang and Lee, 2010; Dai and Kuosmanen, 2014).

Due to multi-criteria approach, the application of DEA is deemed as a suitable SC performance measure. Besides, DEA compares homogeneous DMUs with same goal and vision which is not prevalent in the SC. This leads to bias in the SC performance evaluation process and degrees of freedom issues. In order to reduce the size of the problem for DEA, a pre-requisite setting for grouping *like-minded* trading partners is recommended in SC environment. Taking cue from this, the *Make-Shift* methodology is proposed as an adjustment procedure prior to the application of DEA approach by estimating net dependence effect using analytics. Specifically, the intended methodology explores the relationship between chain partners and client organisation from trading partner's perspective. Further, categorisation is achieved through modifications to the Kraljic's matrix in dependent and independent parameters. The independent parameter (X-axis) for the matrix has criticality of sourcing rank and the dependent parameter (Y-axis) has multi-criteria cumulative score. However, the multi-criteria dependent parameters are obtained through interaction parameters from trading partner perspective. In this research, dependent parameters ranking of scheduled, received and accepted quantity; total delivery and quality performance; main customers; business share; years in relationship; and types of components supplying are considered to arrive at an overall cumulative score. Independent parameter ranking is put through criticality of sourcing components using scaling techniques in alignment with the goal of selected company. Besides, relevant measurement scales are adopted from logistics literature to ensure reliability and validity of the proposed model. By virtue of this, relationship between trading partner and client organisation is looked into the individual quadrant of the Kraljic's matrix. Moreover, cooperation types can be better understood using cluster analysis (Schmoltzi and Wallenburg, 2011) and segregating trading partners in to *like-minded* group primarily deals with categorising rather than ranking (Wu and Barnes, 2012). Finally, validation of the *like-minded* group of trading partners is conducted using Spearman's rank correlation test. This is carried out by estimating the strength of relationship between *'best-peer'* and remaining peer DMUs in individual quadrant. However, results from the *Make-Shift* methodology yielded strong positive relationship across the *like-minded* trading partners. Therefore, this methodology leads to elimination of bias factor in the assessment process for further DEA evaluation. In order to address trading partners situated on the border line of the quadrant, *k*-medoid cluster analysis is adopted for the optimisation of initial group using similarity measures. In particular, Euclidean distance between the conflicting cluster-specific *best peer* DMUs and trading partner on the border line is calculated. From the minimum distance attained, trading partner under consideration is grouped accordingly. In this way, operational issues for grouping trading partner on border-line cases are demonstrated. Another aspect of research looked at assigning variable importance among dependent parameters through a consensual approach. For this reason, dependent parameter weights are derived by estimating the average value of individual contribution in a coalition group through *Shapley value* function in a cooperative approach.

In the next step, a multi-stage performance evaluation framework is developed using DEA considering the transaction based inputs-outputs from buying organisation perspective. At this stage, DMU corresponds to the different categories of suppliers and LSPs. The proposed framework considers time dynamics as an influential factor along with discretionary, non-discretionary and categorical formulations by combining DEA and econometric models. In particular, the proposed approach of dynamic evaluation captures variable inter-temporal effects between the inputs-outputs signifying output disposability relaxation for individual trading partner. Also, combining the perspectives of other discipline broadens the knowledge spectrum of the specific domain (Kauppi, 2013). In this thesis, analysis of the trading partners (suppliers and LSPs) is carried out through multi-stage improvements from static to dynamic consideration in five stages. Specifically, output oriented DEA model is applied under c-RTS and v-RTS. The inputs-outputs for performance evaluation are considered from the operations perspective of 4PL transaction centre. In this thesis, quantity scheduled and main customers to the supplier are considered as inputs. Conversely, quantity accepted, types of components and revenue spend in USD are regarded as outputs for supplier evaluation. Performance evaluation with respect to static consideration is conducted through improvements on basic DEA (CCR) model under discretionary, non-discretionary and categorical formulation (stage 1 to 4). In the next stage, dynamic evaluation (stage 5) is carried out by estimating lagged parameters for individual trading partner through Vector Auto Regression (VAR) model signifying relaxation in output disposability function. By incorporating the attained lag parameter values to the static DEA dataset, dynamic inputs-outputs are obtained. By virtue of these inputs-outputs, evaluation of DEA is carried out for evaluating dynamic performance. On similar lines, LSPs are evaluated considering consignment order frequency as input along with weight shipped and revenue spend as outputs. In the next stage SE, TE and PTE for all the different categories of trading partners are computed under both RTS characterisation. By virtue of this, sources of inefficiency are analysed along with providing improvement directions for individual trading partner to become efficient. In order to address tie-situation in the efficiency scores, super-efficiency DEA model is adopted to differentiate among trading partners for further evaluation. Also, projection scores obtained from the evaluation results are considered for leveraging cross-segment integration (For instance: merging suppliers and LSPs) in the 4PL transaction centre. Verification of the developed performance evaluation framework is conducted using system efficiency DEA model by projecting individual trading partner scores to the efficient frontier. In parallel, statistical validation of the proposed framework is performed using Wilcoxon Mann-Whitney rank sum test. By virtue of the above mentioned procedure, an exclusive 4PL performance measurement framework to create a *best of breed* trading partner setup for the transaction centre is presented.

Subsequently, the 4PL transaction centre is created by extending Bogetoft and Wang's (2005) production economics integration model for carrying out cross-segment mergers from operations perspective. Specifically, a two-tier cross-segment integration framework considering performance and cost orientation is proposed for the transaction centre. Here, DMU corresponds to the virtual merger of suppliers and LSPs. To link evaluation and integration, projected outputs of suppliers and LSPs are considered as inputs along with common output (cost of supplier and LSP integration). In particular, projected *Quantity Accepted* in supplier evaluation and projected *Weight Shipped* relating to LSP evaluation are proposed as inputs and combined *Revenue Spend* is regarded as common output. In the first tier, optimal mergers are selected through OE parameters which consider cost and technical aspects simultaneously. Moreover, categorical formulation is adapted based on the segregation attained from the proposed *Make-Shift* methodology. Also, performance of cost aspects is identified through AE. In case of tie-situation in OE score, least merger cost is looked as a second tier approach. The proposed cross-segment integration framework reduces operations cost, improves flexibility to handle demand uncertainty and utilises resources effectively by arriving at optimal standards for integration. The recommended model of transaction centre is evaluated by comparing the merger cost of trading partners between the legacy (actual) situation and the proposed model outputs. Further, adequacy of the intended model is assessed considering precision and accuracy of the operating standards utilising Concordance Correlation Coefficient (CCC) and Model Efficiency Statistics (MEF). Here, rationale for using CCC relates to its ability to evaluate the values predicted by the model with respect to precision and accuracy simultaneously. MEF statistics explains the proportion of variation between the actual and the model predicted values (Tedeschi, 2004).

Further, assessment of the suggested model is conducted through data variation in two segments by dividing the dataset into training and verification dataset. In segment-1, the proposed multi-stage performance evaluation framework is applied for both the datasets to arrive at dynamic DEA efficiency scores. Consequently, the consistency of the attained results is verified using mean and variance statistics under both RTS characterisation. Validation of the intended framework is performed through bi-lateral DEA comparison technique along with non-parametric statistics. In segment-2, evaluation of the proposed cross-segment integration framework for the 4PL transaction centre is carried out with regard to consistency and adequacy. Here, model consistency is captured using OE parameters and model adequacy is critically analysed using decomposition of Mean Square Error of Prediction (MSEP). In addition, system efficiency DEA model is utilised to validate the derived operating standards of merger efficiencies. In the next stage, stability of the derived operating standards from the proposed model is verified using window analysis (Cooper *et al.*, 2006, 2007). Sensitivity analysis for the optimal mergers is carried out by estimating the stability region for individual cross-segment mergers using Abri *et al.*'s (2009) framework by classifying mergers into efficient, quasi-efficient and inefficient category. Moving forward, cross-validation of the sensitivity region is performed employing Wilcoxon signed-rank test. With all the collated results, the final check integration of cross-segment trading partners is carried out by assimilating range of scenarios to make inferences. The proposed research of this thesis contributes to the theoretical advancement with regard to cross-segment integration in the 4PL domain by considering the dynamic capabilities. The model also provides operating standards which can help the buying organisation opting for 4PL to know the capabilities of chain members in order to synchronise outside competencies with internal resources.

In order to make the recommended model robust, distinguished features and characteristics are embedded as extensions. Here, DMUs refer to individual suppliers and LSPs. To retain unutilised trading partners in the transaction centre, OE based heuristic ordering mechanism is proposed based on the output of the proposed model as the first extension. In what follows, a consensual approach to share the total merger spend is suggested in a sub-optimal way for a stipulated time period. Moreover, this extension provides trading partners a fair chance to escalate themselves to join the *best of best* 4PL setup. The second extension to the transaction centre model deals with achieving trade-off between policy decisions and system constraints for selecting optimal number of trading partners using multi-objective programming and DEA technique. The third extension relates to generation of the optimal route plan considering delivery time of trading partners using unified optimisation methodology which combines mathematical programming techniques and heuristics.

In the last phase of model development, an exclusive proactive risk-predictive model is developed for the 4PL transaction centre in two phases. In the first phase, risk assessment of the existing trading partners in the transaction centre is carried out using Handfield and McCormack's (2007) framework to ensure continuous supply of components. In the second phase, risk predictive model is developed using Neural Network (NN) methodology considering randomly selected five castings supplier from various geographical locations. In this regard, the different normalised training dataset is presented to the NN until actual and predicted Risk Probability Index (RPI) match. Finally, the viability of risk model is ascertained by presenting verification dataset to the NN. Nonetheless, apt number of predictors for risk modelling is obtained scientifically from Partial Least Square (PLS) regression (Ritchie and Brindley, 2007). Finally, the complete results are collated and findings are reported with appropriate justifications. Besides, individual situations for the 4PL transaction centre is proposed, modelled, implemented and verified with an application case study. In addition, the coordinator of transaction centre can be facilitated to make decisions scientifically and proactively satisfying accuracy and precision requirements. In the next section, a brief discussion about the company considered for a case study is presented.

3.4 Brief about the Company Considered for Case Study along with Justification for 4PL

Busse and Wallenburg (2011) highlighted that the case study approach is viewed as the most appropriate research design for topics in nascent stage. Moreover, a case study should signify what data shall be collected, analysis of data and findings of the proposed research (Yin, 2003). Soni and Kodali (2011) further supported that dealing with the case study approach in

SCM research helps to understand the topic of 4PL research in depth. On the other hand, Kutlu (2007) pointed out difficulties and challenges to find companies for the 4PL case study as it involves collection of enormous amount of secondary data. Soni and Kodali (2011) found that only five percent of empirical research is carried out in the developing countries. Further, the authors reported that industry sector like agriculture is not very well explored through empirical research. This led to an impetus to consider Agri-based tiller-tractor Original Equipment Manufacturer (OEM) for a case study of this research. In parallel, Busse and Wallenburg (2011) expressed that 4PL service provider needs to be more innovative and promote industry-specific research in order to meet global challenges. Thus, VST Tillers Tractors Ltd. (VTTL), a Bengaluru-based farm equipment manufacturer is considered for a case study to validate the proposed research.

Main product categories include power tillers and low horse power tractors (sub 30 HP) along with their accessories used in the agricultural sector. The company incorporated in 1967 is promoted by the VST Group, a well-known business house in south India situated at Whitefield, an industrial hub, in Bengaluru. Besides, the company has 75,000 sq. m. of land with a built up area of 15,000 sq. m. approximately. The company started with the production of power tillers and single cylinder diesel engines. Further, the company has technical collaboration and joint venture with Mitsubishi Heavy Industries and Mitsubishi Corporation, Japan for manufacturing power tillers and diesel engines. In 1984, VTTL entered into an additional technical and financial collaboration with Mitsubishi Agricultural Machinery Company Ltd., Japan for manufacturing compact 18.5 HP four wheel drive tractor. Figure 3.8 portrays the representation of power tillers and tractors respectively. Detailed product specification for tillers and tractors is reported in Appendix A.1. Currently, manufacturing capacity of the company is 25,000 power tillers and 5,000 tractors annually. VTTL is also certified by ISO 9001:2008 Quality Management System (QMS) since 1998 to cater the customer needs holistically. The selected company is considered as an undisputed market leader in the Indian tiller market enjoying more than 45% market share (Sushil Finance, 2011). In order to stay in sync with the market condition, VTTL has its own Research and Development (R&D) centre to facilitate new product development and existing product upgrades. Besides, the company exports its product to Middle East, Africa, Russia and Turkey.

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Shakti 130 DI Power Tiller

Shakti MT180D Tractor with Rotary

Figure 3. 8 Main products of VTTL

Source: VTTL website

The company also imports machinery from other countries such as rice trans-planters, combine harvesters, garden tillers, reapers, hedge trimmers, bush cutters and hole diggers. As tillers and tractors contribute to the major portion of manufacturing, this research study dwells upon component suppliers and LSP details for these products. Moreover, the growth of tiller and tractor manufacturing industry is dependent on the availability of Government subsidies and bank finance to farmers. Alternatively, the company is importing Chinese power tillers in completely knocked down form under the brand name "*Dragon Shakti*" to tap lower-end tiller market. According to the agricultural equipment market outlook report for 2017, the labour scarcity and Government subsidies drive agri-mechanisation in Indian scenario. Thus, demand for farm equipments is viewed to increase ~ 4% cumulatively during 2012-17 (Sushil Finance, 2011). For instance, demand in Asia-Pacific for agri-equipments doubled in 2011. The company reported USD 103 million turn over in the year 2013-14 (Khatua, 2014). In the next section, VTTL's SC is elucidated along with their current operations process.

3.4.1 VTTL SC Operating Procedures

The existing SC of VTTL is analysed using process flow diagram as depicted in fig. 3.9. Moreover, this type of process flow diagram helps to visualise the entire scope of SC and enables process improvement strategies.

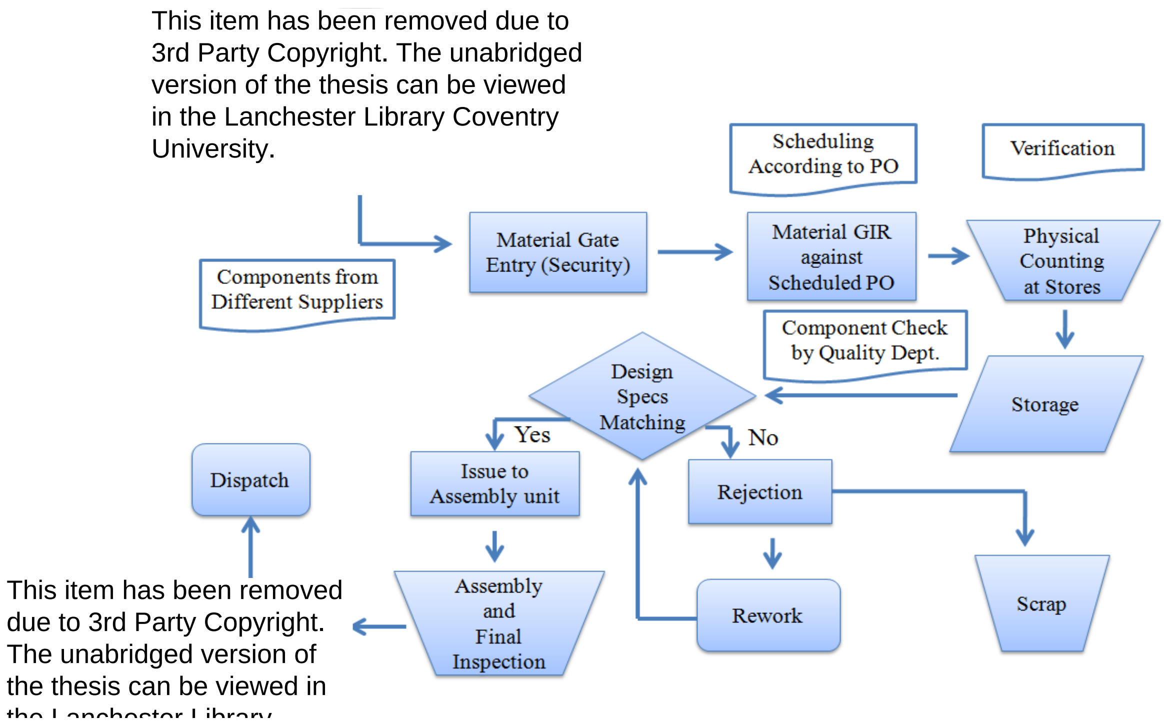

Figure 3. 9 SC of VTTL

The main function of VTTL comprises of assembly operations with more than 90% of the components and sub-assemblies procured across India from more than 250 suppliers. Specifically, tillers contribute to 60% and tractors add to 25% of revenues. Thus, the quality of VTTL products is enormously dependent on the effectiveness of supply from the vendors. This can be achieved by setting up an optimal SC process. In particular, all the stake holders of the company know VTTL's requirement signifying cooperative approach for mutual benefit. The company has developed a vendor manual highlighting the procedure for approving vendors along with the guidelines to conduct performance evaluation. VTTL's Supply Chain Procurement (SCP) team expects all the different categories of suppliers to be ISO certified and provides technical assistance for those vendors who have not enrolled to QMS. The quality policy of VTTL reported in the vendor manual is as follows:

- *Supplying Quality Products with High Reliability at Competitive Price*
- *Providing Efficient and Prompt After Sales Service*
- *Achieving High Degree of Customer Satisfaction through Continuous Improvement Process*
- *Minimising Product Cost while Maintaining High Quality and Reliability*

In addition, VTTL has communicated to all the vendors for aligning their quality policies based on the above mentioned policy. The main objective of the company ensures that VTTL products made by the employees should be ***'Best in the Field'***. The final assembly of tiller and tractor products broadly comprise five categories of components in the form of Gears and Shaft, Castings, Sheet Metal, Turned and Machined, and Proprietary items. Accordingly, the suppliers are classified in the above mentioned categories and various LSPs are utilised for material movement from vendor destination to the company. VTTL has developed a questionnaire (Appendix A.2) for vendor assessment based on QMS, Top Management Responsibilities, Resource Analysis, Product Realisation, Measurement and Analysis. By virtue of this questionnaire, individual scores for each vendor can be calculated. Based on the attained score, grades are derived as shown in table 3.1.

Table 3. 1 VTTL vendor grading mechanism

Grade	A			B			C
	A	A+	A++	B	B+	B++	
Score	89 to 94.9	95 to 96.9	97 to 100	75 to 80	80 to 84.9	85 to 88.9	< 75

The company expects all the vendors to be in grade A and provides support to the grade B vendors in identifying their directions for improvement. In principle, grade C vendors are not preferred by VTTL in the long run. In addition, the company expects all the third-party vendors to maintain following documents at any given time:

- *Document and Records Control Report*
- *Calibration Report of Measuring Devices*
- *Corrective and Preventive Action Report*
- *Non-Confirming Product Control Report*

Besides, VTTL look for new vendors whenever there is a single source dependency and the existing suppliers are not capable of supplying prescribed quantity with quality. In addition, VTTL's multi-disciplinary team comprising of professionals from SCP, quality, design, finance and manufacturing visit the premises of prospective vendor before incorporating them in Approved Vendor List (AVL) through vendor registration form (Appendix A.3). Initially, SCP department places a trial order of 500 number with the vendors which facilitate them to develop necessary tooling and facilities. Initially, a sample lot of 20 number is supplied which comprises of appropriate inspection reports along with chemical and metallurgical reports. If required, VTTL team visits the premises of vendor to ensure adequate processes and tooling are adopted during this stage. In the next phase, VTTL places pilot orders of 100 number and demands relevant inspection reports for the same. Similarly, this procedure continues till the trial order quantity is achieved. Based on the acceptance of pilot orders, the new vendor registration process is completed and the details are updated in VTTL's master document. Further, the company places bulk orders after finalising commercial aspects in consultation with the vendor by issuing the purchase order. The sample purchase order issued to the vendor by VTTL is reported in Appendix A.4. This order consists of detailed technical requirements of the component along with the commercial terms and conditions. If the trial orders are not accepted, the vendors are given one more chance to deliver fresh samples with corrective action plans. After the purchase order is generated, the component delivery from the vendors is initiated with respect to the schedule which can be weekly, monthly or quarterly. In the SC process of VTTL, every vendor is evaluated based on quality requirements and delivery schedule using Vendor Quality Rating (VQR) as per Appendix A.5 and Total Vendor Rating (TVR) as per Appendix A.6. Quantity for each vendor is allocated by the SCP buyer based on their VQR and TVR ratings.

In the first stage, different categories of components arrive through specified 3PLs to VTTL's materials gate. Here, the consignment is verified as per the schedule and the purchase order number before directing it to the stores department. At this point, component samples are sent to the quality department for checking specifications as per the design. Based on the approval from quality division, Goods Inward Receipt (GIR) is generated by the stores department and the same information is shared with the finance department for processing payment. Moreover, different categories of components have dedicated bays in the stores department. Consequently, the components are sent to the tiller and tractor assembly line respectively. On the other hand, rejected components are sent to rework or scrap based on the criticality of deviations observed. Also, quality related data in GIR is captured through IC-Soft ERP to estimate the inspection code in the range of 1 to 5. Here, inspection code of 1 is given for complete acceptance of the lot; 2 is specified for minor deviation in the lot. Similarly, 3 or 4 is set for major deviation or rework on a case by case basis. The inspection code all the way through 1 to 4 is suitably estimated based on the quality of components (see Appendix A.5). But, inspection code 5 relates to bulk rejection due to suppliers fault. The format for recording GIR number along with inspection code is documented in the table 3.2.

Table 3. 2 GIR number with inspection code format of VTTL

Sl. No.	GIR Date	Part Name and Number	Quantity Received	Quantity Accepted	Quantity Rejected	Inspection Code	Remarks in GIR
1						1	
2						2	Minor Deviations
3						3	Rework Advised
4						3	Segregated

In summary, VQR is calculated in the first week of every quarter namely January, April, June, and October corresponding to the current year. The attained results are printed and circulated by SCP buyers to the vendors. During this stage, VTTL's SCP division makes necessary recommendations by suggesting corrective and improvement actions along with visiting the premises of vendor for technical assistance, if required. Whenever the VQR is consistently low by a particular vendor, VTTL looks for alternative sources to achieve sustainability of the SC operations. Finally, TVR is calculated to assess the capability of vendor in order to supply the prescribed quantity on the scheduled date. Vendors with modest capabilities for special processes like heat treatment, plating or painting should outsource the processes with VTTL recognised sources. Conversely, the vendors with outstanding performance with complete acceptance of components in the past history are called as self-certified vendor. Here, the inspection report is sent by the vendor itself and the VTTL quality department randomly inspects their components periodically.

The company follows "*make to stock*" production policy with fixed target on a day to day basis. Besides, annual production plan is derived to balance supply and demand markets in alignment with organisation's growth strategy. By virtue of this master plan, monthly and daily targets for the production department are devised. For instance, production plan for the year 2008 - 09 is shown in table 3.3.

Table 3. 3 VTTL production plan

	Tiller	Tractor
Annual	18000	3000
Monthly	1500	250
Daily	60	10

In principle, all the stakeholders of the company are expected to abide and plan for achieving VTTL's annual production plan seamlessly. Thus, planned and achieved monthly target in numbers is displayed at key places in the company as depicted in table 3.4 to track production status along with action plans. The same information is also shared to VTTL's trading partners in order to enable co-operative situation in the SC environment.

Table 3. 4 VTTL production details

Product	Production in Numbers	Jun.-08	Jul.-08	Aug.-08	Sept.-08	Oct.-08
Tiller	Planned	1300	1590	1585	1585	1440
	Achieved	1415	1519	1550	1480	1200
Tractor	Planned	250	250	250	250	270
	Achieved	191	202	140	150	150

For vendor evaluation, past data of the decision variables selected for individual category of trading partner (suppliers and LSPs) are collected through RFIs. In particular, RFI is formulated based on quality, cost, design and delivery capabilities as depicted in Appendix A.7. Besides, SCP department has AVL to procure materials along with dedicated LSPs for material movement. Moreover, these trading partners are evaluated on a quarterly basis to verify their performance trends. Based on the attained results, root cause for non-adherence of performance is analysed. By virtue of this process, every trading partner in the network is made aware of their standing and accountability in terms of their value contribution. In addition, the component details are maintained based on Bill of Materials which includes part name and number, vendor name, price and quantity per unit as shown in table 3.5.

Similarly, the inventory management system of components is classified based on the price range of individual components. For instance, classification of sheet metal components based on their price range is reported in table 3.6.

Table 3. 5 Format for collating details of components

Sl. No.	Part Number	Part Name	Vendor Name	Present Price In Rupees	QTY./ Unit
1	A920187	Handle Stay			1
2	H45453	Arm Tension Pulley			2
3	A920829	Plate			1
4	A9210924-C	Upper Cover			1
5	H43188A	Wheel Rim 'A'			2
6	H43188B	Wheel Rim 'B'			2
7	A920781	Frame Engine			1

Table 3. 6 Price range classification for sheet metal components

Material	Price Range in USD	No. of components
Category – ‘A’	3 and above	22
Category – ‘B’	1 to 3	16
Category – ‘C’	Up to 1	56

Similarly, delivery performance is monitored by the SCP department through delivery date and quantity supplied. By virtue of this, delivery interval is estimated by considering ratio of total number of deliveries in a month to the 25 working day month. In the same line, average supplies for the month is estimated as shown in table 3.7. This helps the SCP buyer to develop the delivery and quantity schedule for different categories of suppliers and LSPs.

Table 3. 7 Format for delivery and supply trend analysis of sheet metal supplier

Part No	Part Name	Suppliers	Delivery Interval		Average Supplies Per Month
			Days	Qty.	
A921007-3	Handle Chassis	Supplier 1	25	400	400
		Supplier 2	3	150	1200
A921003-A	Rotary Frame 540	Supplier 1	5	60	300
A921033-A	Rotary Frame 600	Supplier 1	2	130	1600
A920781	Engine Frame	Supplier 3	7	200	400

In summary, scheduling of component deliveries is developed by the SCP buyers in consultation with stores, quality and production department. This is carried out through the rolling schedule mechanism which contains firm, tentative and projected schedule as depicted in fig. 3.10.

VST TILLERS TRACTORS LTD.										
CASTINGS SUPPLIER		FIRM SCHEDULES				TENTATIVE SCHEDULE				PROJECTED SCHEDULES PER MONTH
		Jul-10				Aug-10	Sep-10	Oct-10	Nov-10	
SCHEDULE DATES		WK1 07/07/10	WK2 14/07/10	WK3 21/07/10	WK4 28/07/10					DEC-10 TO MAY-11
PO NO:	11PO1/PRC/782									
A9210102	PULLEY SHAFT	300		300		1000	1000	1000	1000	1000
C0060100431	SHAFT DRIVE ROTARY									
H430701	SHAFT MAIN		600		600	900	900	900	900	900
H430801	COUNTER SHAFT	700		600		900	900	900	900	900
H430851	SUBMISSION SHAFT		600		600	900	900	900	900	900
H451001	INTERMEDIATE SHAFT	400		500		900	900	900	900	900
H451051	SHAFT ROTARY MISSION		600		600	900	900	900	900	900
H45420-A1	DRIVING - 54CM ROTARY									
H45420-C1	DRIVING - 60CM ROTARY	500		500		600	600	600	600	600

Figure 3. 10 Current scheduling process showing conversion of tentative to firm flow

The process of converting tentative to firm schedule is performed based on the inventory status of components at the stores department. For that reason, material requirement planning is conducted and shared with all the component suppliers. The following formulae are used for converting tentative to firm schedule based on inventory present or no inventory present data of individual component:

- **During end of the month whenever physical inventory is present**

  Tentative to Firm Calculation for (x+2) Month = Tentative schedule (x+2) - (x^{th} month plan – x^{th} month production) - (opening balance - minimum inventory)

- **During end of the month whenever physical inventory is not present**

  Tentative to Firm Calculation for (x+2) Month

  = Tentative schedule (x+2) - (x^{th} month plan – x^{th} month production)

Based on the above calculations, weekly requirement planning is created from the rolling monthly schedule in alignment with the production requirements. Specifically, this rolling schedule comprises three month confirmed and tentative schedule respectively as shown in fig. 3.11. Based on the inventory status and delivery schedules, deviation analysis is carried out to identify areas of improvement in the supply process.

Sl. No.	Description/Part Number	Confirmed Schedule												Tentative Schedule			
		Oct-08				Nov-08				Dec-08				Jan-09			
		1st WK	2nd WK	3rd WK	4th WK	1st WK	2nd WK	3rd WK	4th WK	1st WK	2nd WK	3rd WK	4th WK	1st WK	2nd WK	3rd WK	4th WK
1	BKT-TOP BELT COVER																
2	BKT-BOTTOM BELT COVER																
3	GUIDE PLATE																
4	COVER AIR BREATHER																

Figure 3. 11 VTTL rolling schedule format

After the assembly operations, final integration check is carried out before dispatching to the dealers. The downstream part of the SC is well-connected with dealers and distributors across the nation and equipped with spare parts supply along with service tools. Moreover, standard operating procedures are created in the form of technical literature like instruction manual in addition to providing adequate training to the dealers personnel (technical and non-technical). Besides, the quality department interacts with the end users or farmers and take their opinion into consideration for improving the product. In principle, VTTL accepts positive suggestions for the improvement of SC system from all the vendors. The tiller and tractor manufacturing industry looks for insulation through subsidy scheme of Government policy and competition risks. Whenever the production falls below the target level, it creates uncertainty in the entire SC affecting delivery schedule for different categories of suppliers leading to a Bull-Whip effect. Hence, a strong SC system is necessary for effective material flow to support the manufacturing activities satisfying demand requirements. As per the company policy, tentative schedule cannot be reduced to more than 10% of the estimated number. Thus, giving rise to issues to maintain the inventory levels based on current material requirement planning and delivery schedule in the present scenario. In addition, the process of calculating VQR and TVR involves weights which are subjective in nature. Being a market leader in the tiller and tractor segment, VTTL needs to adopt contemporary methods to cope up with the competitive scenario. Further, the company is betting big in agri-mechanisation while competing with Japanese and Korean brands in India. As nearly 70% of mechanisation comes from micro farming, there is a huge opportunity for the growth of tillers and tractors industry to increase food production (Khatua, 2014). The company is also exploring opportunities to maintain its leadership position in the Indian market. Therefore, VTTL is planning to diversify the current 18.5 HP tractor portfolio in to 22 HP and 26 HP in the next couple of years. In parallel, scaled investments are being planned for technology and SC up-gradation by evolving strategies to reinforce the market share by aiming at 15% to 20% growth. In particular, the company is looking at redesigning their SC as one of their projects to improve operational efficiency and profits. Therefore, the company is contemplating to incorporate 4PL service provider as an appropriate option to manage supply proactively. As 4PL concept is in the nascent stage, modelling transaction centre focusing on implementation and operation characteristics is deemed critical and warranted. By virtue of the 4PL framework, VTTL is expecting operations cost reduction and enhancing relationship with the different categories of trading partners. Hence, 4PL with a transaction centre approach as depicted in fig. 3.12 is deemed appropriate for VTTL to be the frontier in the tiller and tractor industry.

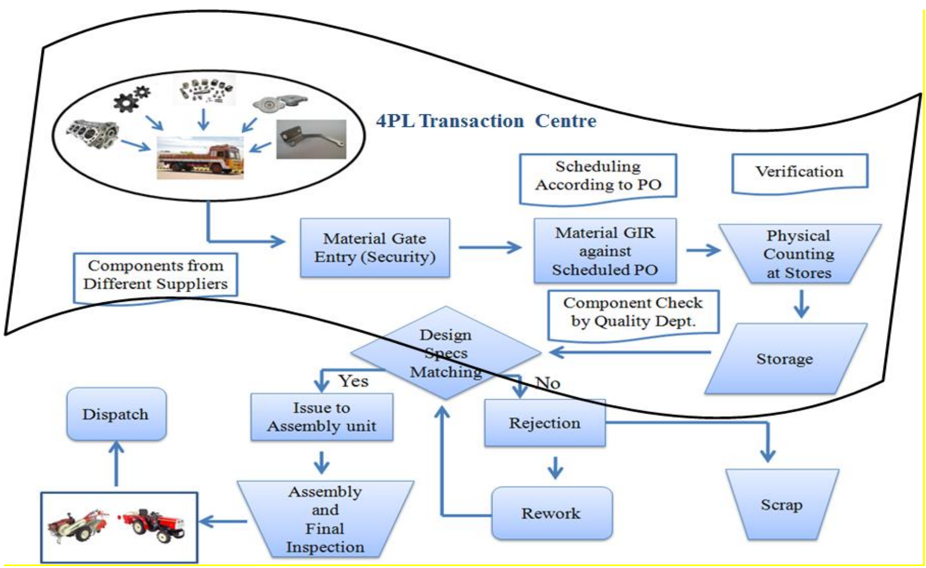

Figure 3.12 Proposed 4PL SC of VTTL

Thus, rationale for the problem statement is formulated which can add value to the literature and solve industry problem. In addition, industry support letter for carrying out research is reported in Appendix A.8. In this thesis, data related to upstream trading partners (LSPs and suppliers) are considered. Besides, the proprietary component suppliers' are not considered due to non-availability of data. In summary, the research study aims to attain un-interrupted supply of components to the assembly process by leveraging stability in the 4PL framework with minimal variation. In the next chapter, an exclusive performance measure to create a *best of breed* 4PL setup is proposed, formulated, implemented and validated.

CHAPTER 4: EVALUATION OF TRADING PARTNERS FOR 4PL TRANSACTION CENTRE

4.1 Prelude to 4PL Transaction Centre

4PL should be flexible and capable to handle the robustness of integrating various category of trading partners (Hingley *et al.*, 2011). Besides, 4PL is deemed as an appropriate business model whenever deep and mutual cooperation are required for dealing with complex and long-term relationship (Prockl *et al.*, 2012) in the SC. However, scarcity of information on 4PL transaction centre development is already discussed in section 2.3. In order to make a 4PL network successful, relationship with different category of trading partners should be maintained effectively. This can be achieved by standardising the operational process and defining business rules for 4PL activities (Kutlu, 2007). Hence, modelling transaction centre that provides operating standards to coordinate SC activities is considered essential for 4PL development. Therefore, an effective approach to coordinate the cross-segment mergers through specialised competencies is deemed vital.

Prior to modelling the transaction centre, it becomes necessary to understand its working principles. Basically, a transaction centre deals with operations process and implementation characteristics for integrating trading partners (Fulconis *et al.*, 2007). Specifically, it acts like a mediator among a constellation of firms. Thus, good understanding of the transaction centre is required for the 4PL service provider to act as an integrator. Figure 4.1 shows the conceptual framework of 4PL transaction centre which consists of suppliers and LSPs as trading partners with cluster-wise categorisation. Here, the *best of breed* suppliers and LSPs are classified based on the regional boundaries known as clusters. Moreover, the 4PL transaction centre provides a platform for cross-segment integration of different category of trading partners and verifies the optimised merger. This helps the coordinator of transaction centre to provide operating standards for cross-segment integration. In summary, the proposed model suggests that a particular supplier has to be merged with appropriate LSP to yield maximum efficiency and economies of scale through resource integration. In this chapter, different categories of suppliers and LSPs under study are also known as DMUs.

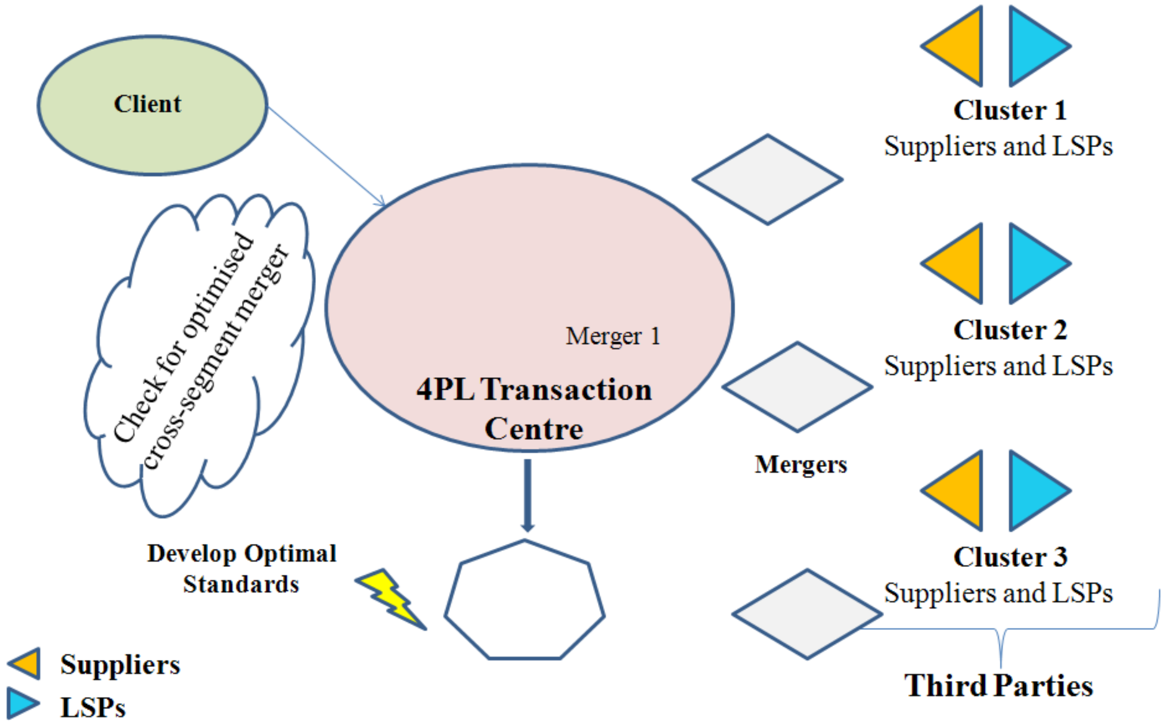

Figure 4. 1 Conceptual framework of 4PL transaction centre

Nonetheless, scarcity in the implementation role of 4PL service providers for trading partner integration is already reported in section 2.4. Thus, creating a vacuum to model 4PL transaction centre from operations perspective. Further, capability to integrate different category of trading partners is identified as one of the key requirements before selecting the 4PL service provider (Kutlu, 2007). In summary, transaction centre that can deal with a range of cross-segment mergers is developed, implemented, evaluated and verified to support 4PL operations. This thesis models the proposed transaction centre of 4PL in two steps. In the first step, an exclusive 4PL performance measurement framework to create a *best of breed* trading partner set up is carried out. Based on the critical analysis of performance evaluation results, directions to become *best of breed* setup with respect to different categories of trading partner are presented. The second step deals with integrating *best of breed* cross-segment trading partners in the form of a merger to achieve economies of scale and optimal results. Specifically, this chapter presents the first step of modelling transaction centre. In the next section, rationale for developing a new 4PL performance measurement framework for creating a *best of breed* trading partner set up is critically analysed.

4.1.1 Background Study

As 4PL is still in the infancy stage, there is a critical need to validate its value addition which can be qualitative or quantitative (Hammervoll and Toften, 2010). 4PL acts as an integrator by assimilating the future uncertainties proactively (Tejpal *et al.*, 2013). Also, 4PL's strength is linked to selection and coordination of the right set of network members (Bourlakis and Bourlakis, 2005; Ozrifat *et al.*, 2014). Therefore, neglecting the process of trading partner selection (Palanisamy and Zubar, 2012) can impact the 4PL vendors overall performance. Prajogo and Sohal (2013) warranted for a closely integrated 4PL SC which can respond to the dynamic situations of the current business environment. The proposed model of 4PL transaction centre should aim for effective outputs and every network members should focus on the entire SC rather than their forte (Fulconis *et al.*, 2007; Ogulin *et al.*, 2012). This creates rationale for the development of efficient operating standards to carry out cross-segment integration in the 4PL transaction centre. In order to create this type of 4PL setup, a *best of breed* pool of different category of trading partners is essential (Fulconis *et al.*, 2007; Richey *et al.*, 2009). For this reason, an exclusive 4PL performance measurement framework which considers both buyer and trading partner perspective is warranted to achieve completeness in the evaluation process (Narasimhan *et al.*, 2001; Wu and Barnes, 2012). By virtue of this performance measure, a balanced approach with holistic view point is attempted from operation's perspective. Moreover, development of a new performance measure is a complex process as it involves dealing with relationship between different category of network members (Kang and Lee, 2010). Kotzab *et al.* (2011) reported that fragmented literature on SCM theory is growing exponentially using various multi-disciplinary domains signifying lack of universal consensus. Gopal and Thakkar (2012) reported that large scope for research exists to address the issues in SC performance measurement despite considerable evidence from the literature. Hence, 4PL service providers should have an exclusive performance measure which can evaluate the trading partners and assimilate the individual capabilities by identifying the sources of inefficiency. The performance measure should portray the way forward from current status to becoming one of the *best of breed* trading partners in a 4PL setup. Further, the strategic development of trading partners is considered as key areas of 4PL improvement (Win, 2008). In addition, this type of an exclusive 4PL performance measurement framework extends the theoretical frontiers of logistics research.

Weber (1996) highlights meagre work is carried out to develop multi-criteria techniques for trading partner evaluation. De Boer *et al.* (2001) reviewed available trading partner selection methodologies carried out by organisations. The authors collectively stressed that most attention is paid for the choice phase of trading partner by ignoring multiple criteria and their qualification. Conversely, studies showed increase in the bottom line performance of trading partners through long term relationship (Seetharaman *et al.*, 2004). Seydel (2005) supported shift in the performance evaluation trend from single-criteria approach to MCDM methods. Further, the author suggested applying OR techniques to support decision makers which is mainly used for operational and logistical problems. However, other areas of decision making such as make or buy, evaluation of trading partners have gained limited attention. In addition, development of inter-disciplinary models for performance evaluation is warranted (Sachan and Datta, 2005) along with data mining tools (Raorane *et al.*, 2012).

Wu and Barnes (2012) developed a multi-stage model of performance evaluation for trading partner selection. Stage-1 focuses on the pre-requisite categorisation of trading partners and stage-2 formulates the mathematical model for optimizing the decision parameters with reference to categorisation attained in stage-1. Besides, trading partner development through training and co-development of product is considered as an evolution in SCM (Seydel, 2006). Organisations are undergoing transition from '*control through ownership*' to '*control through relationship*' with their chain partners (Win, 2008). This led to the growing interest in understanding trading partner's relationship with the client organisation for long-term strategic initiatives (Singh, 2011). Hence, the relationship requires greater involvement of DMUs in the transaction centre multi-dimensionally for leveraging 4PL value. Zhang and Huo (2013) highlighted that SC relationship includes factors like trust, power, commitment and dependence. Specifically, buyer-supplier cooperation can be attained through trust and the participating network members agree to share resources to undertake collaborative problem-solving projects. Tejpal *et al.* (2013) reviewed the meaning of buyer-supplier trust and reported that one party should have the past information of other party.

In order to assimilate buyer-supplier relationship precisely, Leeuw and Fransoo (2009) and Bourlakis and Bourlakis (2005) collectively warranted for the application of portfolio models to assimilate the relationship between trading partners and client organisation. The portfolio models are widely used to segregate the trading partners into *like-minded* group. Yin and Khoo (2007) reported portfolio model classifications and characteristics adapted from Dubois and Pedersen (2002) as shown in table 4.1. Kraljic's matrix is deemed as an appropriate portfolio model for categorising the trading partners in SC environment (Yin and Khoo, 2007; Luo *et al.*, 2009; Luzzini *et al.*, 2012). Naslund and Hulthen (2012) further complimented that clustering *like-minded* trading partners' leverage strategic cooperation through effective resource integration. The authors also highlighted the difficulty in attaining *like-minded* group in a practical situation. Therefore, cluster analysis is suggested to reduce the entire supply base in to smaller group objectively (De Boer *et al.*, 2001; Mukhopadhyay and Setaputra 2006). The cluster analysis utilises classification algorithms for grouping trading partners into *like-minded* group with minimal variations (Ordoobadi and Wang, 2011).

Hertz and Alfredsson (2003) applied a portfolio model using Kraljic's matrix for classification of 3PL based on customer adaptation and problem solving capabilities. Further, Furlan *et al.* (2006) provided a framework for grouping trading partners and found that value of the product and scope for customisation is considered as important theoretical propositions. Zachariassen (2008) applied Kraljic's matrix using qualitative factors in dependent and independent parameters with respect to relationship type (arm's length or co-operative partnership) and negotiation strategies (integrated or distributive).

Luo *et al.* (2009) overcame the qualitative nature of the Kraljic's matrix by quantifying the independent and the dependent parameters into High and Low of the axis.

Table 4. 1 Portfolio models for assimilating buyer-supplier relationship

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Source: Dubois and Pedersen (2002)

Further, the portfolios can be segregated into four types based on their individual relationship in a two by two matrix along the axis as shown in fig. 4.2. Here, the characteristics of each quadrant can be explained distinctively considering suppliers as trading partner. Buying organisations should look for building long-term relationship with strategic suppliers and aim for continuous supply from preference suppliers. Similarly, strategies of multiple sourcing must be adapted for leverage suppliers and cost reduction should be focused for routine suppliers. This matrix investigates strengths and weakness of individual trading partners leveraging more visibility in the evaluation process.

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Figure 4. 2 Kraljic's matrix

Source: Luo et al. (2009)

Conversely, Williams (2010) presented Kraljic's matrix to segregate the trading partners in to different portfolios for dealing with complex relationships. Figure 4.3 shows the Kraljic's matrix which has spend on X-axis and vulnerability on Y-axis. Spend on the X-axis can be objectively measured but vulnerability to change on the Y-axis has to be estimated using SC analytics (Raorane *et al.*, 2012). In general, DMUs under acquisition cluster is considered low profile, where in, the buying organisation has no strategic potential to develop relationship. Here, cost of changing trading partners is low. Hence, DMUs in this quadrant is considered less important and imply no point in developing deeper relationship. Similarly, DMUs in the profit quadrant combine low strategic potential with high spend yielding one-sided relationship. Here, the client organisation takes major turnover of the trading partner's business leveraging no advantage in developing relationship.

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Figure 4. 3 Generalised Kraljic's matrix

Source: Adapted from Williams (2010)

Security quadrant DMUs have low profile with the buying organisation even though strategic potential exists. Here, a buying organisation does not have much attention from the trading partner. Lastly, DMUs in the critical quadrant have high strategic potential for strong relationship where in both parties matter to each other. Due to common approach, this quadrant should divert most of the client organisation's time and resources to improve relationship with trading partners. In addition, benefits of strategic relationship include product innovation, risk mitigation, reduction in working capital and facilitates product differentiation (Jones *et al.*, 2010). But, clustering trading partners using Kraljic's matrix has two main weaknesses. Firstly, the matrix is considered as one sided ignoring trading partner's perspective. This will not portray trading partner's perception about the buying organisation. Secondly, vulnerability to change factor is ignored.

Singh (2011) presented coordination matrix of SC based on dependence as independent parameter and categories of driving power as dependent parameters attained through the output of ISM. This driving power and dependence matrix helps the coordinator to assimilate the inter-dependence relationship between trading partners. But, dependent parameters attained through ISM are subjective in nature leveraging scope for bias in the categorisation process. Prockl *et al.* (2012) called for standardised empirical approach to comprehend the relationship between trading partners and buying organisations. Drake *et al.* (2013) proposed a portfolio model for purchasing by addressing the weaknesses of Kraljic's matrix. Here, AHP technique is used to position components in the quadrants of the Kraljic's matrix based on the complexity of products. But, criteria weights attained from the AHP technique in MCDM environment are highly dependent on the dynamics of decision makers. On the other hand, Kraljic's matrix lacks theoretical foundation and standardised metrics (Luzzini *et al.*, 2012). In order to address this issue, TCE is applied to provide appropriate theoretical evidence for operationalisation of models. Based on TCE principles, transaction between trading partners include asset specificity, uncertainty and frequency. However, this type of model fails to accustom with the type of product (functional or innovative). Thus, Kraljic's matrix with modifications is deemed appropriate to segregate the trading partners into *like-minded* group objectively (Luzzini *et al.*, 2012).

In this thesis, Kraljic's matrix is used to segregate *like-minded* group from trading partner's perspective as an initial pre-requisite mechanism. In particular, independent and dependent parameters are modified based on the spectrum of problem definition (Kang and Lee, 2010). Besides, this type of pre-requisite setting requires application of analytics to cluster the trading partners into focused group for the 4PL setup. Therefore, incorporating SC analytics based on multi-attribute ranking for individual parameters to estimate net dependence effect has become necessary to counter subjectivity issues (Mortensen and Arlbjorn, 2012). Specifically, the dependence from SCM perspective deals with organisation's requirement to maintain relationship with trading partners to reduce opportunism and uncertainty (Narasimhan *et al.*, 2009; Jones *et al.*, 2010). But, application of MCDM methodology to estimate net dependence effect from trading partner's perspective is limited. Thus, a pre-requisite approach is warranted for grouping *like-minded* network members from trading partner perspective as an initial step to develop an exclusive 4PL performance measurement framework.

The next stage of 4PL measure development involves analysing trading partner performance from buying organisation's perspective. Forslund and Jonsson (2007) reported key requirements of the performance measure to achieve common strategy between suppliers and customers (client organisation) as shown in fig. 4.4.

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Figure 4. 4 Key activities of performance measure

Source: Forslund and Jonsson (2007)

The performance measure comprises five steps which includes identifying decision variables, setting targets, defining metrics, measurement and analysis. Based on the problem statement, appropriate decision variables along with metrics can be considered and suitable targets can be set accordingly. Finally, measurement and analysis of the decision variables facilitate achieving common strategy between both the parties in a consensual framework. In summary, efficiency evaluation in performance measurement comprise of assessment, control and improvement of operations process (Wu and Barnes, 2012). This situation led to the need for MCDM performance measure for evaluating chain members using DEA approach (Weber, 1996; Wong and Wong, 2008). Moreover, lack of inter-disciplinary mathematical models for performance evaluation is signified (Wong and Wong, 2008) along with the need for incorporating uncontrollable factors (Braglia and Petroni, 2000). In parallel, Groznik and Maslaric (2012) reported scarcity of methodology to carry out SC re-design and developed a framework for SC re-engineering as shown in fig. 4.5. The six step framework's goal is to assist the mechanism for re-designing the SC by identifying two process states known as "*AS-IS*" and "*TO-BE*" situations. Steps 1 to 3 focuses on the current evaluation process (*AS-IS*) of the selected network members. Steps 4 to 6 looks at benchmarking situation (*TO-BE*) by addressing the gap between actual and required situation. Here, '*TO-BE*' state portrays the benchmark level and influences the new performance measures to incorporate this theoretical propositions. In particular, improvement directions can be put forward for individual trading partner through gap analysis and review process.

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Figure 4. 5 Framework for re-designing SC

Source: Groznik and Maslaric (2012)

Taking cue from this, an exclusive performance measure is formulated to create a *best of breed* 4PL setup which can portray ‘*AS-IS’* and ‘*TO-BE’* conditions. This situation is considered important due to the synchronisation between requirements of client organisation and outputs of trading partner (Kutlu, 2007). In order to create a proactive 4PL transaction centre, an integrated framework for performance evaluation under static (time independent) and dynamic (time dependent) consideration (Mukhopadhyay and Setaputra, 2006) is necessary from buying organisation perspective. Chen (2009) looks at dynamic effects by adding lag parameter with time trajectory for evaluating the distribution network. Thus, extending the traditional DEA model to incorporate dynamic effects makes the model practical and realistic from application perspective. Park *et al.* (2010) and Parthiban and Goh (2011) advocated an integrated approach in performance evaluation process signifying domain-specific to holistic perspective. Wu and Barnes (2012) adapted a four phase multi-stage performance evaluation model from Luo *et al.*’s (2009) study based on the dynamic feedback mechanism as depicted in fig. 4.6.

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Figure 4. 6 The four-phase dynamic feedback model for trading partner selection

Source: Adapted from Luo et al. (2009)

The X-axis has trading partner information availability with the buying organisation ranging between low and high. Y-axis has decision parameters of the trading partner based on the problem scope between many and few. Prospecting of trading partners is performed during preparation for DMU selection. Segregation with right set of trading partners is proposed during the pre-classification stage. Here, the buying organisation has little information about the pre-classified trading partners with variety of decision variables to choose from. Based on the classification attained, final selection of the trading partners is conducted with domain specific information and few decision variables. In addition, feedback mechanism is adopted at every phase in the framework to make the performance evaluation process dynamic. In addition, the decision maker has to deal with a diverse challenge of selecting critical input-output parameters in the model building process. Cook *et al.* (2014) demonstrated that the multi-stage performance evaluation DEA framework possesses stronger discrimination power as compared to the conventional DEA. One follow up direction is to develop a stage-wise multi-criteria framework to evaluate trading partners using inter-disciplinary approaches. As a result, the coordinator of transaction centre can identify critical inputs and outputs along with analysing improvement directions. The research findings suggest that initiating collaborative business framework in the upstream part of the SC is easier compared to the downstream section (Leeuw and Fransoo, 2009). Thus, this thesis models the 4PL transaction centre considering suppliers and LSPs of a tiller and tractor manufacturing company. In summary, an exclusive 4PL performance measurement framework is proposed to create a *best of breed* trading partner setup in a balanced approach. Specifically, pre-requisite setting is carried out from trading partner's perspective and performance evaluation is performed from buying organisation's perspective. In fact, the contribution of 4PL can be achieved with cooperation from a *best of breed* trading partner pool. In the next stage, different category of *best of breed* DMUs are integrated in the form of a merger to achieve the ultimate 4PL value. The purpose of this chapter is two-fold which differs from the existing research. In the first part, the *Make-Shift* methodology to cluster heterogeneous trading partners into *like-minded* group for further DEA evaluation is proposed. In the second part, the multi-stage performance evaluation framework is synthesised using inter-disciplinary approaches. The assumptions and parameters considered for the study are reported in the next section.

4.2 Assumptions, Parameters and 4PL Performance Measurement Framework

4.2.1 Assumptions

The assumptions include,

- Multi-criteria data of trading partners has been available through company records in the form of RFI, GIR, schedule and delivery reports, etc.
- Fewer customers to the trading partner signify long-term relationship with the buying organisation and the scope for collaborative relationship exists. Hence, higher ranking has been considered for this parameter
- The principle adopted to select input-output combinations for DMU evaluation follows an analogy of lower the better for input and higher the better for output
- Dynamic performance evaluation framework incorporates only time series inputs and outputs for estimating inter-temporal effects using econometric models. DEA approach has been further applied to the dynamic dataset in order to arrive at efficiency measurement
- To address tie-situation among efficient trading partners, original ranking attained by inefficient DMUs have been retained without any change

4.2.2 Parameters

The given parameters for the study comprise,

- A = Number of Stage 4 DMUs
- B = Number of Stage 5 DMUs
- $C(\ )$ = Characteristic Function
- $C(S_c)$ = Coalition with respect to Characteristic Function
- $\mathbf{H_o}$ **=** Null Hypothesis
- $\mathbf{H_1}$ **=** Alternate Hypothesis
- L = Lower Bound of Binary Decision Variable Z
- $\mathbf{R_s} = (r_{ij})$ = Ranking Score Matrix for ith Criteria and jth DMU
- S = Normal Distribution Statistic
- S_c = Coalition
- T = Trend Variable
- $T_{calculated}$ = Calculated Wilcoxon-Mann-Whitney T-statistic
- $T_{critical}$ = Critical Wilcoxon-Mann-Whitney T-statistic
- U = Upper Bound of Binary Decision Variable Z
- $\mathbf{X}$ = Input Vectors
- X_{ip} = Input i at Time Period p
- $X_n^{p_a}$ = Input at p_a for DMU n
- $\mathbf{Y}$ = Output Vectors
- Y_{ip} = Output i at Time Period p
- $\tilde{Y}_{ip}$ = Dynamic Output i at Period p
- $Y_n^{p_a}$ = Output at p_a for DMU n
- Z_i **=** Binary Decision Variable Satisfying 0 or 1 Condition
- a_i = Intercept i of Regression Equation
- b_j = Output Slope Coefficient of Regression Model
- c = Number of Dependent Parameters
- d = Euclidean Distance between Trading Partners p and q
- d_v = Cumulative Score of Dependent Variable

- i_v = Best Peer DMU Rank as Independent Variable
- k = Lag Period Length
- l = Player in the Trading Partner Pool
- n = Number of DMUs/Variables/Trading partners
- p = *Best Peer* Trading Partner in the Respective Cluster
- p_a = Arbitrary Time Period
- q = Trading Partner on the Border-Line of Kraljic's Matrix
- $r_i(S_c)$ = Coalition Score
- superscript C = Controllable Input-Output
- superscript N = Non-Controllable Input-Output
- t^-, t^+ = Input Slack and Output Surplus Variable of Output Oriented DEA Model
- u_{ip} = Impulse Response or Error Term of Regression Equation
- w_i = Weights of Dependent Parameters
- x_o = Input under Study
- y_o = Output under Study
- α = Significance Level, %
- β_j = Input Slope Coefficient of Regression Model
- θ = Input Oriented Efficiency
- θ^* = Optimal Input Oriented Efficiency
- $\boldsymbol{\mu}$ = Column Vector of Inputs and Outputs for DEA Model
- η = Output Oriented Efficiency
- Δ = First Difference Operator
- ρ = Spearman's Rank Correlation Coefficient
- δ = Unit Root
- ε = Non-Archimedean Element

4.2.3 *Make-Shift* Methodology for Clustering Heterogeneous Trading Partners into *Like-Minded* Group

In this thesis, 4PL performance measurement framework has been developed considering different category of component suppliers and LSPs. Further, the suppliers have been classified into Gears (Gi), Castings (Ci), Sheet Metal (Si), Turned and Machined (Mi), and proprietary suppliers where 'i' indicates the trading partner code. Similarly, LSPs (Li) have been categorised into different clusters based on their regional boundaries of operation. Based on the literature review chapter, DEA with modifications has been considered as an appropriate performance measure for SCs. As DEA compares homogeneous DMUs with same goal and vision (Wong and Wong, 2008; Chen, 2009), this type of setup in a SC is not prevalent from a practical view point. This situation has led to the fundamental difference of applying DEA methodology in SC research hitherto. As SC deals with multi-criteria situations, DEA model should comprise all the decision parameters as inputs and outputs ideally. However, this leads to degrees of freedom issues due to the presence of large inputs and outputs with limited industry data (see Equation 3.4). In order to address this issue, an attempt to reduce the size of the problem for DEA has been carried out by grouping *like-minded* trading partners. Hammervoll and Toften (2010) conducted an exhaustive review on buyer-supplier relationship by identifying value-addition enablers. These enablers are further classified into interaction based and transaction specific parameters which focuses on effectiveness and efficiency respectively. Interaction based parameters capture the behaviour of trading partner with past data. For instance, a particular supplier increasing their production capacity without fulfilling buying organisation's future demand indicates that the DMU is interested in doing business with others. Conversely, transaction based parameters include efficiency aspects like dealing with operational issues or resource utilisation. Hence, identification of similar natured trading partners has been performed through interaction parameters and performance evaluation of these categorised trading partners has been conducted through transaction parameters. In this thesis, net dependence effect has been captured from trading partner's perspective to arrive at *like-minded* group. In the next stage, transaction based parameters have been looked for performance evaluation of trading partners from buying organisation perspective. In summary, an attempt to create a *best of breed* set up for 4PL service providers has been proposed in this chapter. The proposed formulation for the 4PL performance measurement framework has been depicted in fig. 4.7. This section proposes the *Make-Shift* methodology to identify *like-minded* group using interaction parameters (highlighted in the below figure) for further DEA evaluation.

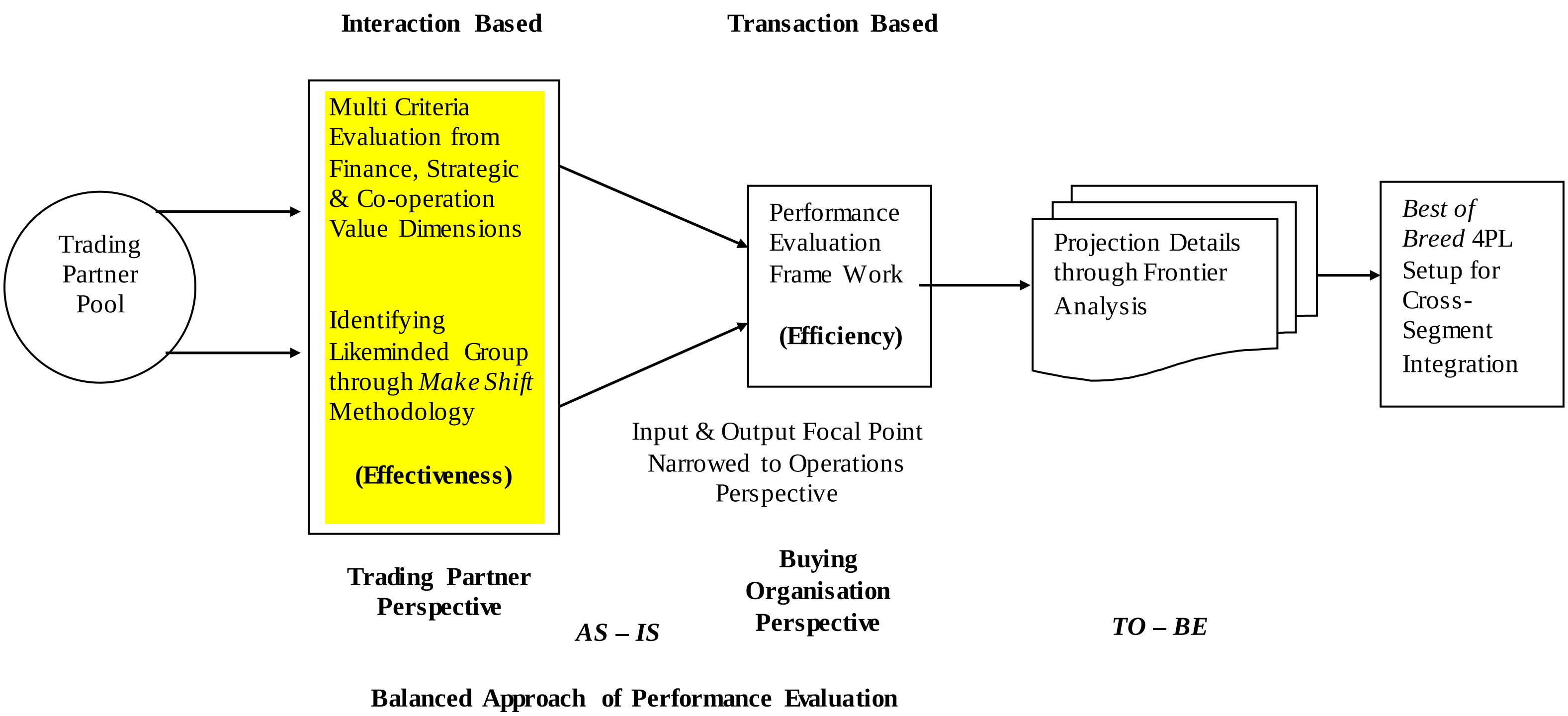

Figure 4. 7 Formulation for 4PL performance measurement framework - effectiveness

In SCM, lack of trust is one of the hindrance factor for information sharing which can be attained with due course of time (Bagchi and Larsen, 2002). Hence, a pre-requisite setting to group *like-minded* trading partners for DEA evaluation is warranted in SC environment. This type of segregation helps the 4PL service provider to assess trading partners' relationship effectively. Further, selecting appropriate trading partners and bringing them together to match the client organisation's requirement has been considered as an important task of the 4PL vendor (Kutlu, 2007). Therefore, synthesising a pre-requisite methodology to select *like-minded* trading partners exclusively for the 4PL framework augments the theoretical advancement. Besides, checking compatibility well in advance minimises risks in the future and reduces heterogeneity among the trading partners (Naesens *et al.*, 2007; Wu and Barnes, 2012) in the long-term 4PL settings. Specifically, identifying the trading partners with right frame of mind facilitates cross-segment integration in the 4PL transaction centre (Cruijssen *et al.*, 2007) by leveraging trust and cooperative relationship (McClellan, 2003). Taking cue from this, the *Make-Shift* methodology to cluster heterogeneous trading partners into *like-minded* groups for further DEA evaluation has been proposed to support 4PL operations. As the procedure of shifting trading partners into *like-minded* group is temporary due to the dynamic nature of 4PL network (Kutlu, 2007), this procedure has been named as the *Make-Shift* methodology.

Most of the assessment procedures portray buying organisation's perspective but fails to understand the relationship from trading partner's perspective (Bourlakis and Bourlakis, 2005; Songailiene *et al.*, 2011; Leeuw and Fransoo, 2009). To address this gap, estimation of net dependence effect from trading partner's perspective (Leeuw and Fransoo, 2009) has been attempted for a 4PL business setting. In particular, application of MCDM methodology (Kutlu, 2007) to estimate net dependence effect using SC analytics has been put forward using the past performance of trading partners. Here, decision variables for SC analytics has been considered from trading partner's perspective to assimilate their relationship with the buying organisation. This captures the *like-minded* trading partners for further performance evaluation. Specifically, the intended methodology explores the relationship between chain partners and client organisation from trading partner's perspective. This leads to elimination of bias factor in the assessment process for further DEA evaluation in the 4PL transaction centre. Therefore, the estimation of net dependence effect becomes logical to comprehend the relationship that has to be maintained between both organisations. Hence, the rationale for study has been to address the weakness of DEA principle in SC environment. Ambrose *et al.* (2010) found that both buyers and suppliers have different relationship understanding on each other. Hence, segregating trading partners in to *like-minded* group helps the coordinator to map individual relationship.

In order to identify decision parameters from trading partner's perspective, an exhaustive review has been conducted on trading partner evaluation in SC domain. Songailiene *et al.* (2011) developed a conceptual model for assimilating factors from trading partner's perspective as depicted in fig. 4.8. The trading partner perspective model comprises of three value dimensions in the form of financial, strategic and cooperation value. The main drivers of financial value include profit/revenue generation along with risk reduction. Strategic value driver includes long-term relationship building through knowledge creation and sharing. Lastly, cooperation value enabler deals with developing trust between the network members.

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Figure 4. 8 Conceptual model to assimilate factors from trading partner perspective

Source: Adapted from Songailiene et al. (2011)

By virtue of these drivers, industry specific parameters can be considered based on the scope of problem statement. Besides, interaction parameters have been collated from trading partner operation's perspective using financial, strategic and cooperation dimensions in table 4.2.

Table 4. 2 Interaction parameters from trading partner operation's perspective

Sl. No.	Interaction Parameter	References	Dimension
1	Financial Health, Business Share or Competitive Pricing	Dickson (1996) Min and Joo (2006) Jharkharia and Shankar (2007) Sarkis *et al*. (2007) Thakkar *et al*. (2008) Ambrose *et al*. (2010) Songailiene *et al*. (2011) Singh (2011) Luzzini *et al*. (2012) Vaidya and Hudnurkar (2013) Drake *et al*. (2013) Ozrifat *et al*. (2014)	Financial Value

2	Quality	Dickson (1996) Sarkis *et al*. (2007) Singh (2011) Luzzini *et al*. (2012) Drake *et al*. (2013) Vaidya and Hudnurkar (2013) Ozrifat *et al*. (2014)	Strategic Value
3	Consistency in Business Relationship	Drake *et al*. (2013) Ozrifat *et al*. (2014)	
4	Reputation (Trust)	Dickson (1996) Min and Joo (2006) Jharkharia and Shankar (2007) Thakkar *et al*. (2008)	
5	Delivery on Time	Gunasekaran *et al*. (2001) Singh (2011) Bennett and Klug (2012) Luzzini *et al*. (2012) Vaidya and Hudnurkar (2013)	
6	Commitment	Sarkis *et al*. (2007) Ozrifat *et al*. (2014)	
7	Capacity	Sarkis *et al*. (2007) Ozrifat *et al*. (2014)	
8	Different Types of Product (Innovation)	Jharkharia and Shankar (2007) Songailiene *et al*. (2011) Luzzini *et al*. (2012) Vaidya and Hudnurkar (2013)	
9	Communication or Willing to Share Resources	Dickson (1996) Min and Joo (2006) Thakkar *et al*. (2008) Hammervoll and Toften (2010) Ambrose *et al*. (2010) Songailiene *et al*. (2011) Bennett and Klug (2012) Vaidya and Hudnurkar (2013) Daim *et al*. (2013) Drake *et al*. (2013) Ozrifat *et al*. (2014)	Cooperative Value

The above mentioned references act as evidence for the selected decision parameters in this thesis. Brief about the interaction parameters has been explained as follows:

1. Business share or competitive pricing refers to the financial transaction between trading partner and buying organisation in the supply network. These details have been obtained from IC-Soft ERP's master procurement sheet and signifies dependability
2. Quality aspect captures arriving at a potential fit with respect to product standards between both the parties. Total Quality Performance (TQP) is utilised to assimilate quality performance for a pre-defined period through the secondary data obtained through IC-Soft ERP's received versus accepted sheet
3. Consistency in business portrays relationship between the network members for long-term strategic planning. This has been captured using RFIs (*see sl. no. 1 of RFI*) by estimating the relationship in years
4. Reputation deals with building trust across the value chain based on the past business performance. This can be analysed based on acceptance quantity report of the product for a particular time period using secondary data from IC-Soft ERP
5. Delivery on time refers to the capability of product supply by meeting deadlines through commitments. Total Delivery Performance (TDP) is used to analyse the lead time performance using secondary data attained from IC-Soft ERP's scheduled versus received sheet
6. Commitment portrays reaction of the trading partner for scheduled quantity. Hence, received quantity data of the product is analysed to elucidate commitment efforts through secondary data utilising IC-Soft ERP
7. Capacity distribution of the trading partner capture details of the associated business partners. Also, willingness of the trading partner to allocate specific production share has been analysed through RFIs (*see sl. no. 1 of RFI*)
8. Innovation deals with knowledge capabilities to make different types of product. This has been captured through RFIs (*see sl. no. 1 of RFI*) based on the number of different type of product categories in the past five years
9. Communication captures the cooperative value dimension across the network. For instance, communication measures the supplier tendency to react for an instruction given

by the company. Here, responsive supplier enables the company to schedule more quantity, thus, scheduled quantity report is considered utilising IC-Soft ERP

In summary, the above mentioned parameters consider diverse literature in a single platform from theoretical and practical implications. On the contrary, additional empirical research is needed to support the relationship structure across *like-minded* trading partners (Soni and Kodali, 2011; Wieland and Wallenburg, 2013). Thus, Kraljic's matrix is applied to categorise single type of network members into different portfolios. Moreover, this type of a two-by-two matrix is widely used (Lee and Drake, 2010) and categorises the trading partners into four quadrants. Specifically, dependent and independent parameters for clustering can be user-specified along with considering multiple criteria (Dai and Kuosmanen, 2014). Hence, modifications to the Kraljic's matrix in order to capture trading partner's perseverance towards the buying organisation have been proposed. Figure 4.9 portrays the modified Kraljic's matrix in alignment with the considered company goal.

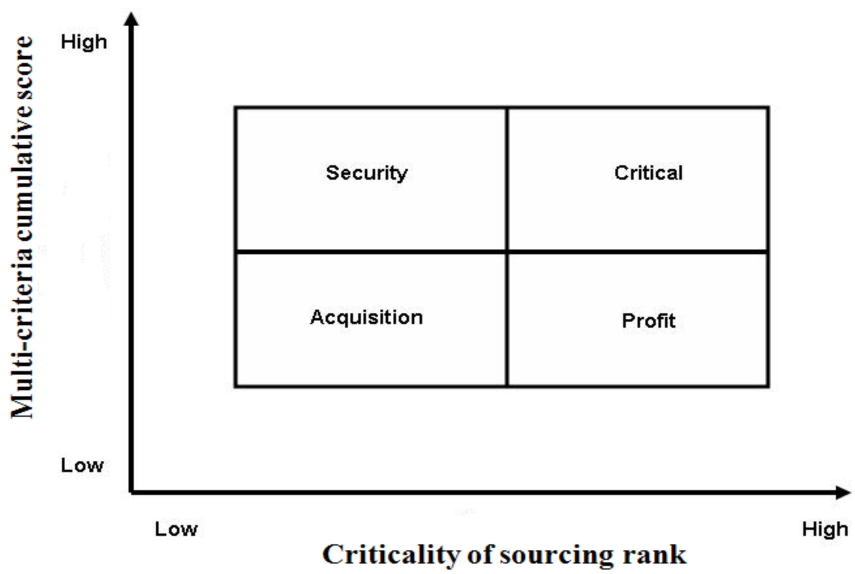

Figure 4. 9 Modified Kraljic's matrix

In this thesis, Kraljic's matrix has been applied to 4PL domain for assimilating the relationship from trading partner's perspective. By virtue of this, the coordinator of transaction centre can understand the net dependence on each trading partner along with their potential to add value for 4PL performance. The X-axis has criticality of sourcing rank (independent parameter) and the Y-axis has multi-criteria cumulative score (dependent parameters). Criticality of sourcing has been obtained through component-wise scaling techniques through ABC analysis with respect to the end product and ranking has been attained in decreasing order. In principle, category 'A' means difficult to develop the source, category 'B' signify moderate difficult and category 'C' imply easy to develop the source. Based on the number of 'A' category components, ranking has been given in decreasing order. Once the consideration of 'A' category components has been completed, 'B' category numerical value has been considered in decreasing order. In case of tie in 'A' category, subsequent numbers in 'B' category has been compared and ranking has been carried out. Similar procedure has been applied for 'B' and 'C' category components too. By virtue of this, ranking for criticality of component sourcing has been carried out in decreasing order. Conversely, multi-criteria cumulative score has been attained by adding individual dependent parameter ranks. Here, the decision parameters has been selected from the trading partner perspective from table 4.2. Based on the confidence interval and actual value, ranking for individual criteria has been obtained. Further, the consolidation of the ranking by considering multi-criteria dependent parameters has been carried out to arrive at cumulative score. Specifically, individual criteria ranks have been added to arrive at a cumulative score. Based on the attained score, lesser the value infers better the trading partner analogy. Nonetheless, tie-situation between the trading partners is given the same rank by eliminating the next subsequent rank. Moreover, scope has been defined for a particular time period and relevant data has been collected. The rationale for selecting ranking mechanism is inspired from the findings of Daim *et al.* (2013) which yielded similar results whenever *like-minded* trading partners are present.

In order to divide the matrix into four quadrants, respective median values of independent and dependent score have been considered objectively. Based on the corresponding independent and dependent score, trading partners have been plotted in the modified Kraljic's matrix. In this way, the heterogeneous group of trading partners has been segregated in to *like-minded* group. Furthermore, this procedure adheres to the necessary and sufficient conditions of DEA formulation for SC performance evaluation. Thus, elimination of the bias factor prior to performance evaluation across heterogeneous network members in the distribution network has been viewed as a pre-requisite setting. In addition, trading partner's perception towards the buying organisation has been captured by mapping individual relationship. The proposed methodology enhances buying organisation to estimate the net dependence with each trading partner based on their position in the Kraljic's matrix. Likewise, the concentration to evaluate trading partners can be shifted to lower quadrant. In summary, DMUs must be compared in individual quadrant and then progress towards the next significant quadrant. The inference helps to identify *like-minded* groups and subsequently DEA evaluation for that specific cluster has been carried out accordingly. Hence, the suggested *Make-Shift* methodology assists the coordinator of transaction centre to assimilate relationship before evaluating individual DMUs for 4PL operations.

Viability of the *like-minded* group has been validated in individual quadrants using Spearman's rank correlation coefficient test ρ (Aczel and Sounderpandian, 2008). This test explores the relationship between dependent (d_v) and independent variable (i_v) ranks using expression 4.1 for n variables.

$$\rho = \frac{n\sum d_v i_v - \left(\sum i_v\right)\left(\sum d_v\right)}{\sqrt{n\left(\sum i_v^2\right) - \left(\sum i_v\right)^2}\sqrt{n\left(\sum d_v^2\right) - \left(\sum d_v\right)^2}} \quad \text{.........................} (4.1)$$

In this work, d_v signifies cumulative score and i_v deal with *best peer* criticality of sourcing rank of the respective cluster. The recommended *Make-Shift* methodology has been ascertained by estimating the strength between '*best-peer*' and '*other peer*' DMUs in individual clusters. Dai and Kuosmanen (2014) further suggested carrying out ranking in the descending order with respect to individual cluster and enable trading partners to look at *peer* DMUs for benchmarking.

After plotting the attained dependent and independent parameter score, some trading partners might be on the cluster borders. In order to address this type of operational issues, the optimisation of the initial grouping has been carried out using similarity measures. In this thesis, *best peer* DMU in the specific cluster is considered as the reference set for optimising the initial group. Here, *best peer* DMU represents the trading partner with highest criticality of sourcing rank in a particular cluster. For this reason, *k*-medoid clustering technique has been adopted (Myatt, 2007) by considering the *best peer* trading partner as cluster centroid. Besides, this type of *k*-medoid partition-based clustering overcome outliers unlike *k*-means grouping process (Myatt, 2007; Aczel and Sounderpandian, 2008). Moreover, the similarity between the trading partners has been assimilated through distance measures (Jaafar, 2012). Due to continuous data, Euclidean distance (d) between the conflicting cluster-specific *best peer* DMUs (p) and trading partner on the border line (q) for n variables has been calculated using expression 4.2.

$$d_{pq} = \sum_{i=1}^{n} \sqrt{(p_i - q_i)^2} \qquad \text{.................................} \ (4.2)$$

Based on the attained minimum distance with a particular cluster (Myatt, 2007; Jaafar, 2012), the borderline DMUs has been grouped accordingly. In this way, threshold for borderline cases have been addressed by considering the minimum Euclidean distance.

Besides, the equal weights have been considered among dependent parameters (Y-axis) assuming the principle that SC's strength is equal to the weakest link in the network (Chopra and Meindl, 2007; Son and Orchard, 2013). The analogy for this assumption believes in promoting equal importance to multi-criteria dependent parameters. In general, every network members of the SC should contribute for adding value to the customer (Win, 2008). Similarly, another line of research looks at having different weights for the dependent parameters to give variable importance for analysis. In particular, different weights for the dependent parameters may be incorporated in the proposed methodology through a consensual multi-criteria approach. This thesis criticises other MCDM methodologies like AHP, ANP etc. which derive weights through a group of decision makers having subjectivity influence. As the scope of study is narrowed to operations perspective, variable weights scheme has been adopted to promote objectivity influence. Moreover, the weights have been derived by estimating individual contribution of the dependent parameters in a coalition group. Specifically, *Shapley value* function (Cooper *et al.*, 2007) is utilised by taking an average value of individual contributions of dependent parameters. By virtue of this, a fair chance for all the parameters in an ordering mechanism has been provided and the weights have been derived in a cooperative manner. Further, the applied consensual approach has an edge over other MCDM methods with respect to variable weight selection like DEA. Here, the weights for the dependent parameters are derived from the data unlike fixed weight scheme which is set in prior.

The formulation for this approach includes n trading partners and c dependent parameters along with the ranking score matrix $\mathbf{R_s} = (r_{ij})$ for i^{th} criteria and j^{th} DMU. The ranking score with respect to dependent parameters has been collected using a questionnaire (see Appendix B.1) from different trading partners. Each trading partner is deemed as a player l in the above setting with weights w_i. By virtue of this setting, the relative importance of player l can be obtained as follows:

$$\frac{\sum_{i=1}^{c} w_i r_{il}}{\sum_{i=1}^{c} w_i \left(\sum_{j=1}^{n} r_{ij} \right)} \qquad \text{.........................} \ (4.3)$$

The numerator portrays player *l's* self evaluation for the given weight and denominator includes total score of all the trading partners as measured by player *l's* weight. In order to derive the weights, the maximisation of the above ratio can be considered as follows:

$$Max \ \frac{\sum_{i=1}^{c} w_i r_{il}}{\sum_{i=1}^{c} w_i \left(\sum_{j=1}^{n} r_{ij} \right)}$$

subject to constraints .... (4.4)

$$w_i \geq 0$$

To generalise the situation, score matrix r_{ij} can be normalised such that:

$$\sum_{j=i}^{n} r_{ij} = 1 \qquad \text{.........................} \ (4.5)$$

By using Charnes-Cooper transformation (Cooper *et al.*, 2007), the above fractional problem can be transformed into LPP as follows:

$$c(\ ) = \max . \sum_{i=1}^{c} w_i r_{il}$$

subject to constraints .... (4.6)

$$\sum_{i=1}^{c} w_i = 1$$

The attained LPP result through simplex method is known as the characteristic function *c( )* and any subset from the trading partner pool is known as coalition S_c represented in { }. The rationale for application of a consensual approach in this thesis eliminates selfish weight selection procedure as demonstrated by Cooper *et al.* (2007). In summary, coalition and characteristic function (represented as $c(S_c)$) of the dependent parameters has been combined and analysed to arrive at individual contribution. The coalition score $r_i(S_c)$ has been calculated as the sum of individual dependent parameter criteria as shown below:

$$r_i(S_c) = \sum_{j \in S} r_{ij} \qquad \text{................................ (4.7)}$$

In this regard, each coalition aims at obtaining the maximum $c(S_c)$ representing a cooperative framework. Moreover, the dependent parameters have been arranged using '←' symbol for formulating the coalition. For instance, if parameter 'b' comes after 'a'; it is represented as 'a ← b'. In principle, all possible coalition combinations have been used to arrive at individual contribution of dependent parameters. Based on the attained $c(S_c)$, decomposition of individual contribution in all coalitions has been calculated as follows:

$$c(S_c) - c(S_c\text{-}\{l\}) \qquad \text{.............................. (4.8)}$$

From the attained individual contributions, *Shapley value* has been applied for deriving weights as a solution procedure. The rationale for applying this function believes the claim that calculating the average value of individual contributions is reasonable (Cooper *et al.*, 2007). In continuation, *Shapley value* can be defined as an average of individual contribution with respect to dependent parameters and deemed as an appropriate function for a cooperative approach. In this way, weights for the dependent parameters have been derived utilising variable weight scheme. In the next stage, development of a multi-stage performance evaluation framework has been formulated, implemented, evaluated and statistically validated.

4.2.4 Development of Multi-Stage Performance Evaluation Framework

After the segregation of network members in to *like-minded* group from trading partner's perspective, performance evaluation has been carried out using DEA from buying organisation's perspective. The rationale for this approach recalls Hammervoll and Toften's (2010) work where transaction specific initiatives have been highlighted as value-addition enablers as shown in fig. 4.10.

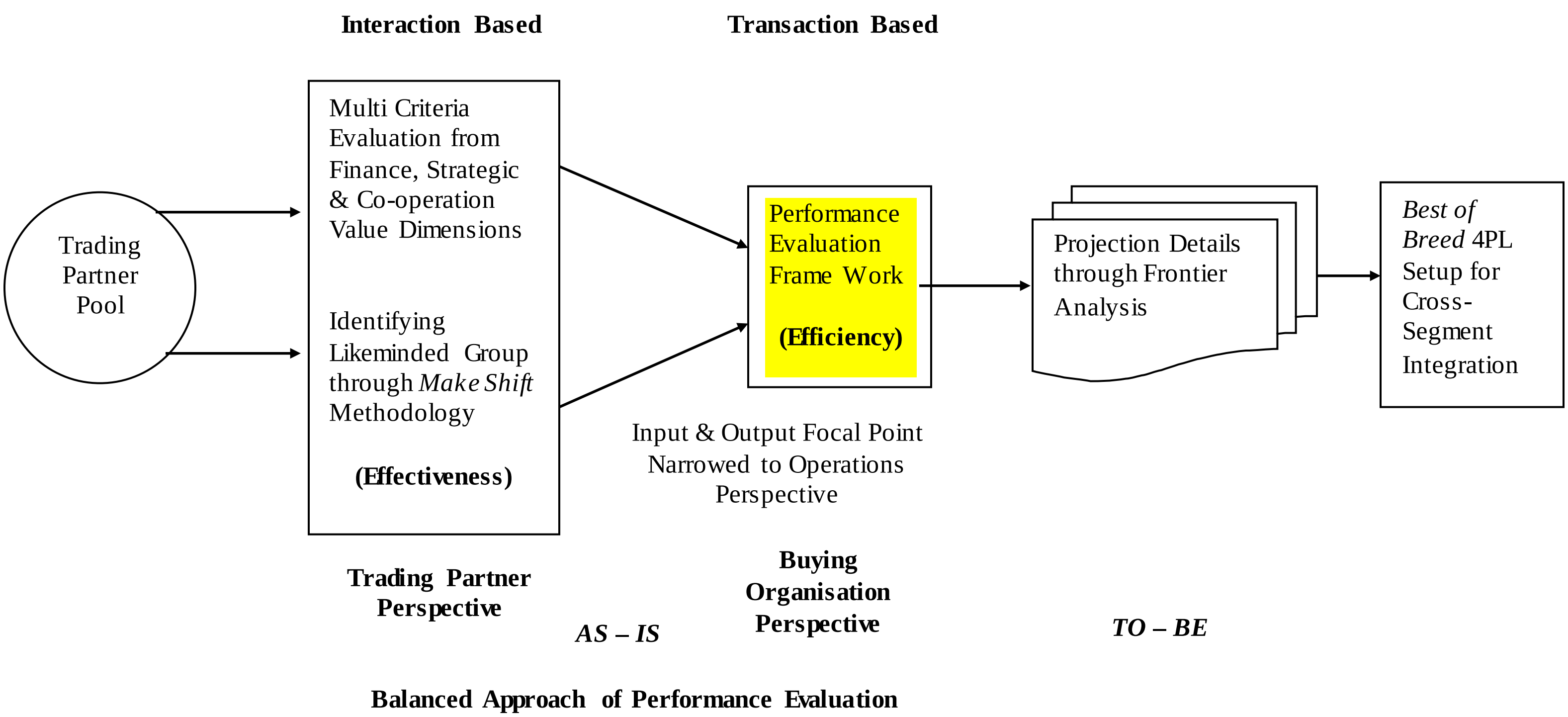

Figure 4. 10 Formulation for 4PL performance measurement framework - efficiency

Luzzini *et al.* (2012), Chen (2009), Visser (2007) and Mukhopadhyay and Setaputra (2006) collectively called for shift from static to dynamic consideration with respect to time for performance evaluation. It has been found that the dynamic performance evaluation approaches assume positive lagged effect across the distribution network (Chen, 2009). But, trading partners in the network differ in size and scope which may have variable carry-over effect. In order to address this gap, multi-stage performance evaluation framework considering static and dynamic characterisations has been developed for the 4PL transaction centre. In particular, a new dynamic evaluation procedure with variable lag effect (positive, neutral or negative) on subsequent chain partners has been formulated to make the model pragmatic and realistic. In this thesis, the selection of specific input-output parameters for DEA evaluation of suppliers and LSPs have been carried out based on the principle of lower the better for input resources and higher the better for output realisation (Cooper *et al.,* 2007; Lau, 2012) from operations perspective. In particular, the input-output parameters have been selected by narrowing down the operational measures into transaction specific parameters of suppliers and LSPs based on the evidence of literature and discussions with the buyers along with data availability (Noorizadeh *et al.*, 2013; Bhanot and Singh, 2014; Gandhi and Shankar, 2014) from the considered tiller and tractor manufacturing company. Kang and Lee (2010) further stressed that the input-output criteria may be added or deleted depending on scope of the SC. Therefore, the probable input-output parameters for the DMUs (suppliers and LSPs) have been identified with 4PL transaction centre operations view point as follows:

Table 4. 3 Transaction parameters for assimilating performance from buying organisation's perspective

Sl. No.	Probable Inputs	References	Probable Outputs	References
1	Operations Cost	Dickson (1996) Gunasekaran *et al*. (2001) Luzzini *et al*. (2012) Vaidya and Hudnurkar (2013)	Revenue Spend	Dickson (1996) Thakkar *et al*. (2008) Bennett and Klug (2012)
2	Production Capacity	Dickson (1996)	Performance or Productivity Output	Dickson (1996) Bennett and Klug (2012) Luzzini *et al*. (2012) Vaidya and Hudnurkar (2013)
3	Regional Proximity/Coverage	Dickson (1996) Vaidya and Hudnurkar (2013)	Types of Components	Dickson (1996)
4	-	-	Asset Utilisation	Vaidya and Hudnurkar (2013)

Brief description of inputs and outputs selected from the above table for supplier performance evaluation in this thesis can be elucidated as follows:

- **Input-1 (operations cost):** Quantity scheduled in numbers deal with the purchase order released based on operating cost satisfaction for the company. However, supply risk of the critical components has to be monitored effectively by avoiding single source dependency. Furthermore, this detail has been collected from the master production sheet for a particular period through IC-Soft ERP
- **Input-2 (production capacity):** Main customers to supplier is one of the non-controllable inputs to the company which do not have control on their operations. This uncovers the company standing with supplier’s capacity for establishing sustainable business and the details have been collated through supplier RFIs (*see sl. no. 1 of RFI*)
- **Output-1 (performance output):** Quantity accepted in numbers enable output of supplier performance in delivering quality product as per the requirement. Also, the supplier reputation increases with the company and the master production sheet for a particular period has been utilised from IC-Soft ERP
- **Output-2 (revenue spend):** Revenue spend in USD establishes stability in the business process which can be attained over a period of time. Here, higher the spend indicates positive transaction and the details have been procured from finance department
- **Output-3 (types of components):** Types of component in numbers highlight the R&D activities of the supplier which can be helpful for developing collaborative projects in the future operations. Moreover, this detail has been obtained through supplier RFIs (*see sl. no. 1 of RFI*)

Similarly, brief description of inputs and outputs selected from table 4.3 for LSP performance evaluation can be explained as follows:

- **Input-1 (regional proximity):** Consignment order frequency in numbers deal with number of times a particular LSP is hired for supply of materials. Equipped with proper and meticulous planning, the company looks at optimising the ordering frequency to LSPs by devising strategies like full truck load, regional coverage etc. Thus, the order frequency parameter has been considered as an input for LSP performance evaluation.

Besides, the secondary data of pre-selected LSPs for a particular region has been obtained through in-bound logistics (stores) department

- **Output-1 (asset utilisation):** Weight shipped in kg is deemed as one of the output which has to increase with LSPs operational performance by pooling suppliers region-wise. Besides, the details of logistics asset utilisation for a particular period has been obtained through company records in the inbound logistics (stores) department
- **Output-2 (revenue spend):** Revenue spend in USD deals with establishing stable business environment with the LSP. Moreover, consistent spend by the company enables dependency on LSPs and details have been collected from the finance department for a particular period

The multi-stage performance evaluation framework has been formulated using five stages of model improvements with reference to basic DEA models in a closed system framework (Davoodi and Rezai, 2014; Matin and Azizi, 2014). Trading partners have been analysed with respect to c-RTS and v-RTS characterisation. The rationale for both RTS portrays long-term plan (strategic) under c-RTS and mid-term plan (tactical) under v-RTS to manage 4PL operations. Mathematical formulation for the intended framework has been carried out in stages as shown in fig. 4.11.

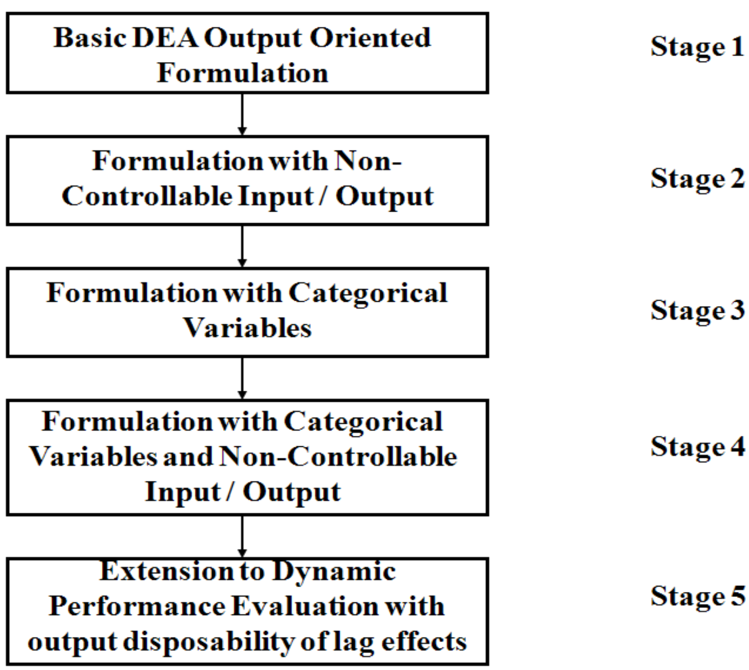

Figure 4. 11 Development stages of the proposed performance evaluation framework

In the proposed model development, improvement from stage 1 to 4 has been carried out under static (time independent) consideration. Analysis in stage 5 deals with dynamic (time dependent) consideration with variable output disposability of lag effects. In addition, static and dynamic evaluation systems has been compared using system efficiency DEA model by projecting all DMU scores to the efficient frontier and statistically validated. Finally, super efficiency DEA model has been applied to address tie-situation in the efficient DMU rankings.

The proposed multi-stage performance evaluation framework has been formulated with output orientation which maximises outputs with existing inputs.

Stage 1:

X and **Y** represent input and output vectors respectively to calculate output oriented efficiency η. The basic CCR output oriented model can be represented for a particular DMU under study (x_o, y_o) with column vector $\boldsymbol{\mu}$ as shown below:

$$\begin{aligned} &\text{Max. } \eta \\ &\text{subject to constraints} \\ &x_o - \mathbf{X}\boldsymbol{\mu} \geq 0 \\ &\eta y_o - \mathbf{Y}\boldsymbol{\mu} \leq 0 \\ &\boldsymbol{\mu} \geq 0 \end{aligned} \qquad \text{…………………..(4.9)}$$

The above LPP model can be solved using simplex method to calculate η. LPP solutions and projections for all the trading partners has been obtained using DEA-Solver (V3) package. The secured results rank the trading partners and signify improvement direction for inefficient DMUs using frontier analysis through projection details.

Stage 2:

An attempt to include non-controllable inputs-outputs has been executed to make the framework pragmatic from application perspective. In the mathematical formulation, superscript **C** signifies controllable and superscript **N** represents non-controllable input or output respectively. For instance, non-controllable input deals with the situation wherein inputs cannot be controlled by the coordinator. The mathematical formulation with non-controllable inputs-outputs has been reported below:

$$\text{Max. } \eta$$

subject to constraints

$$x_o^C = \mathbf{X^C}\boldsymbol{\mu} + t^-$$

$$\eta y_o^C - \mathbf{Y^C}\boldsymbol{\mu} + t^+ = 0$$

$$x_o^N = \mathbf{X}^N\boldsymbol{\mu}$$

$$y_o^N = \mathbf{Y}^N\boldsymbol{\mu} \qquad \ldots\ldots\ldots\ldots\ldots(4.10)$$

Here $\boldsymbol{\mu} \geq 0$; t^- and t^+ represent input slack and output surplus variable for output oriented DEA model respectively.

Stage 3:

In order to evaluate trading partners under MCDM environment, DEA with categorical formulation has been implemented from the attained *Make-Shift* methodology results. In particular, four quadrants of Kraljic's matrix have been represented as category-1 to 4 in a hierarchical manner as depicted in fig. 4.12.

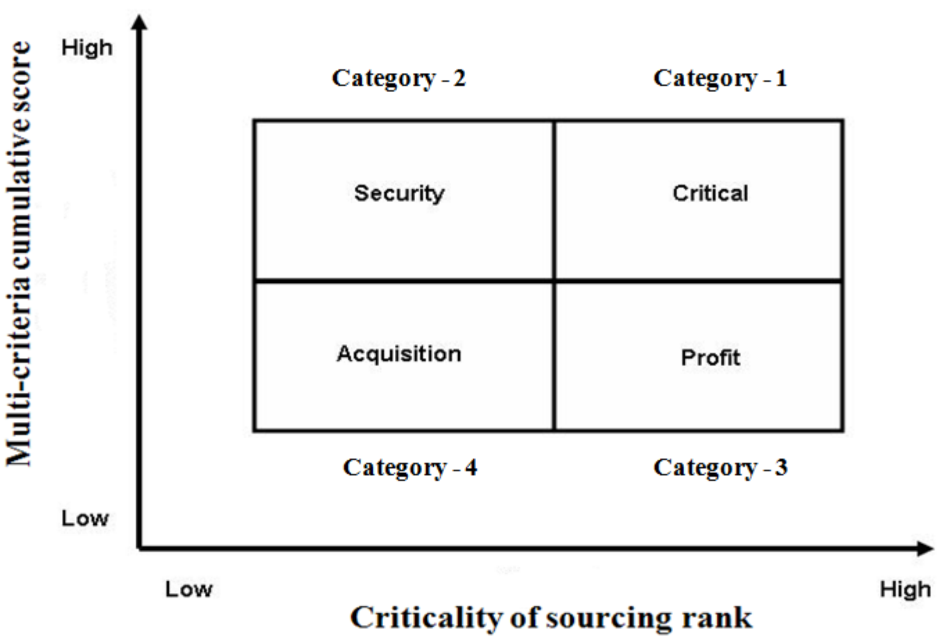

Figure 4. 12 Categorisation in Kraljic's matrix

This effect has been captured in the LPP model by not considering upper category DMUs as basic variables when evaluating lower category DMUs (Cooper *et al.*, 2007). Here, the trading partners in category-1 faces severe competition compared to category-2; similarly category-2 DMUs face significant competition compared to category-3. Lastly, trading partners in category-3 face relatively higher competition compared to category-4 in a hierarchical manner. Therefore, DMUs in category-1 has been evaluated within their group. Similarly, DMUs in category-2 has been evaluated with reference to category-1 and 2. Likewise, trading partners in category-3 has been evaluated with reference to category-1, 2 and 3; and DMUs in category-4 has been evaluated with reference to all other categories respectively.

Stage 4:

In this stage of model development, merger of non-controllable input-output and categorical model has been proposed to capture both effects simultaneously. Although the mathematical formulation looks similar to stage 2, upper category DMUs have not been considered as basic variables during lower category DMU evaluation. As SC branches into different tiers, evaluating trading partners through categorisation makes stage 4 approach logical and conducts performance evaluation process in an apt manner. Moreover, 4PL coordinator has to deal with both controllable and non-controllable input–output parameters for trading partner evaluation (Braglia and Petroni, 2000). Hence, stage 4 model has been viewed as realistic and practical.

Stage 5:

Subsequently, analysis of trading partners has been carried out under dynamic consideration. Here, dynamic factors in the evaluation of SC has been considered important to accurately measure the performance (Chen, 2009). Hence, dynamic inter-relationships have to be incorporated for efficiency measurement of DMUs. In particular, inter-relationship in DEA involves estimating inter-temporal (lag) effects between inputs and outputs (Kao, 2013). However, limited research has been reported in the literature for this aspect (Chen, 2009; Kao, 2013). This study differs from the existing research by capturing distinguished characteristics of lagged effects separately for an individual trading partner. Specifically, variable lag effect between inputs and outputs has been looked across the chain partners since DMUs differ in their scale and size. Therefore, this type of dynamic evaluation leverages fair practices among trading partners in the distribution network. In addition, lagged productive effect signifies input contribution to the current and future outputs. Figure 4.13 portrays k-period lag model for an arbitrary time period p_a for the selected input $X_n^{p_a}$ and output $Y_n^{p_a}$.

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Figure 4. 13 *k*-period lag productive effect

Source: Adapted from Chen (2009)

Here, solid lines infer concurrent effects and dotted line implies lagged effect. This type of performance evaluation has been considered different from the frontier shift methodology as put forward in Malmquist index (Cooper *et al.*, 2007). Moreover, time series data of possible inputs and outputs have been considered for the study. On the other hand, non-time series data have been retained without any change for DEA analysis. In order to incorporate carry-over effect, dynamic lag parameters among inputs-outputs has been quantified using time series econometrics model. Meanwhile, non-stationarity of the dataset has been validated in section 4.3.3 using graphical analysis and Augmented Dicky-Fuller (ADF) test. After validating non-stationarity, the estimation of lag parameters between inputs and outputs for individual trading partner has been carried out through VAR model. Here, all the variables have been considered as endogenous (dependent) variables to give equal weight for inputs-outputs. The term 'Auto

Regression' signifies lagged values of the dependent variable as independent variable in the ordinary least square regression model. Similarly, 'Vector' resembles dealing with two or more variables. For this reason, VAR model has been looked to overcome subjectivity in identifying the dependent and independent variables as criticised by Sims (Gujarati and Sangeetha, 2007). The VAR model for k-period lags with input $\mathbf{X_{ip}}$ and output $\mathbf{Y_{ip}}$ at time period p to yield dynamic output '$\tilde{Y}_{ip}$' is shown in expression (4.11) for corresponding input-output i.

$$\tilde{Y}_{ip} = a_i + \sum_{j=1}^{k} b_j Y_{ip-j} + \sum_{j=1}^{k} \beta_j X_{ip-j} + u_{ip} \qquad \text{.................. (4.11)}$$

b_j represent output slope coefficients and β_j denote input slope coefficients. Similarly, a_i act as an intercept of the regression model. The VAR model to accomplish dynamic output with lag parameters has been represented in fig. 4.14.

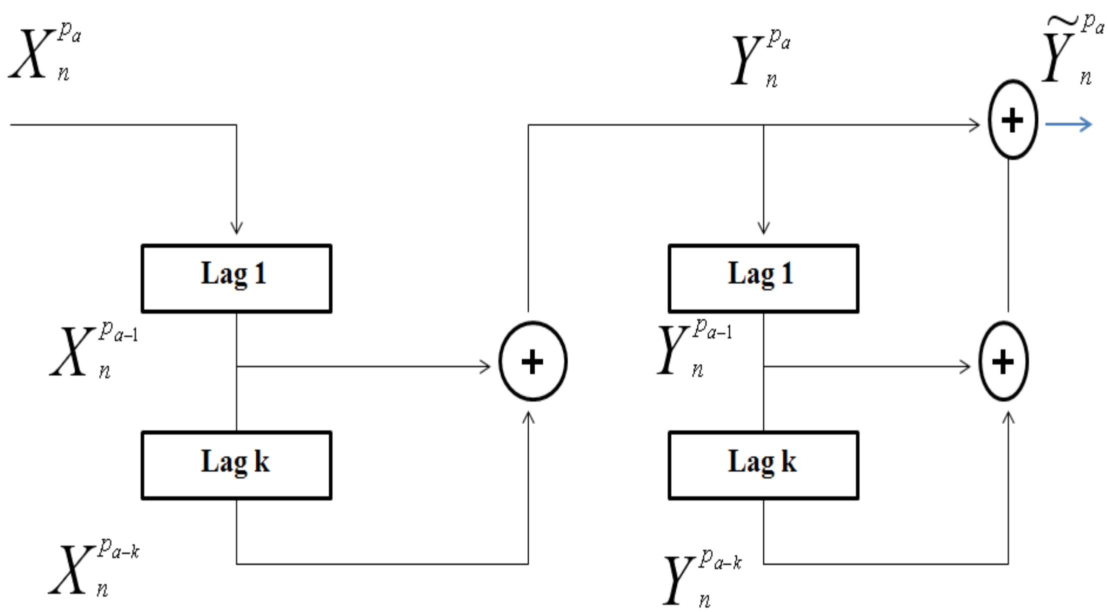


Figure 4. 14 VAR model framework

The k-lag effect of inputs and outputs has been considered along with impulse response function u_{ip} to obtain the dynamic output $\tilde{Y}_{ip}$. Besides, impulse response captures responsiveness of the dependent variable when a shock characteristic is added to the error term. Hence, this function assimilates the entire VAR model behaviour with regard to shock characteristic. In addition, the lag length has been selected reviewing '*Schwarz*' criterion from the dataset. Besides, impulse responses have been obtained through *Cholesky adjusted model* for ordering the variables through Eviews econometrics software. In summary, lag parameters have been obtained for individual trading partners from the VAR model. By incorporating these lag parameter to the static DEA dataset, dynamic inputs-outputs have been attained. In the next step, DEA evaluation has been carried out with stage 4 mathematical formulations for evaluating dynamic performance. By virtue of this, output disposability relaxation has been proposed with variable lag effects which can have positive, neutral or negative impact on the subsequent chain partner. Lastly, stage-wise results have been collated and critically analysed with respect to efficient DMUs, average efficiency and standard deviation. It has been found that static evaluation over-estimates dynamic evaluation process under both RTS characterisation by neglecting the lagged effect in the distribution network. The proposed dynamic performance evaluation approach with variable lag effect has been viewed as one of the original contributions in this thesis.

In the next step, efficiency frontier comparison of static (stage-4) and dynamic (stage-5) performance evaluation models has been performed using system efficiency DEA model. For this purpose, DMUs have been projected to the frontier and combined in the form of virtual dataset (Cooper *et al.*, 2007). As the theoretical distribution of DEA efficiency scores has been statistically independent, it becomes necessary to deal with non-parametric statistics. Hence, Wilcoxon-Mann-Whitney rank sum test has been applied to evaluate difference in statistical significance (Amado *et al.*, 2013). An illustration of system efficiency DEA model and Wilcoxon non-parametric test has been discussed in section 4.3.3. In summary, the proposed dynamic system yielded better results compared to static system. Therefore, the dynamic model has been considered for the study to measure performance effectively. Thus, the developed framework enumerates an integrated approach to perform stage-wise evaluation from static to dynamic consideration in the model building process. This multi-stage framework helps the coordinator of transaction centre to identify critical inputs and outputs to be considered in static consideration. By virtue of dynamic evaluation, the efficiency scores along with projection details provide means to leverage cross-segment integration (For instance: merging suppliers and LSPs). Thus, the proposed multi-stage framework extends the theoretical advancement of the SC performance evaluation literature. At this stage, it becomes necessary to understand the sources of inefficiency by analysing its disintegration. Hence, decomposition of efficiency to estimate SE for individual trading partner has been executed. By virtue of this, the coordinator of transaction centre can evaluate DMUs from strategic and tactical perspective. Furthermore, an individual DMU's area of improvement has been furnished to reach the efficient frontier. This approach makes the performance evaluation framework realistic from the application perspective and relates to SC environment.

Additionally, distinguished features to the developed framework have been incorporated for addressing tie-situations among efficient DMUs using super-efficiency DEA model (Al-Eraqi *et al.*, 2010). This helps the coordinator of transaction centre to distinguish trading partner's performance under tie-situations before considering cross-segment integration for 4PL operations. In general, DEA models have feasible solution when input oriented efficiency $\theta = 1$, $\mu_o = 1$ and $\boldsymbol{\mu_j} = 0$ ($j \neq o$). Hence, an optimal input oriented efficiency θ^* will not be greater than 1. Further, $(\boldsymbol{X\mu}, \boldsymbol{Y\mu})$ outperforms $(\theta x_o, y_o)$ when $\theta^* < 1$. In super-efficiency DEA model, the efficiency scores obtained by elimination of DMU_o data in the constraint results in values $\theta^* \geq 1$, thus, violating the above principle (Cooper *et al.*, 2007; Al-Eraqi *et al.*, 2010). The mathematical formulation for output oriented super efficiency model has been shown in expression (4.12). Here, $j=1, \neq o$ means DMU_o is not included for consideration in the constraint.

$$\text{Max. } \eta - \varepsilon e t^- / t^+$$

subject to constraints

$$x_o = \sum_{j=1,\neq o}^{n} X_j \mu_j + t^-$$

$$\eta y_o = \sum_{j=1,\neq o}^{n} y_j \mu_j - t^+ \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.12)$$

where μ_j, t^- and $t^+ \geq 0$

The objective function has the non-Archimedean element $\varepsilon > 0$ measured by slack t^- and surplus t^+ variables. Tie-situation of efficient DMUs has been ranked in descending order from the attained results of super efficiency model. Therefore, rationalisation of trading partners as a pre-requisite setting and empirical evaluation using DEA methodology has been considered appropriate. Thus, integration of analytics and DEA approach for developing an integrated methodology to create an exclusive 4PL performance measurement framework for the transaction centre contributes to the theoretical advancement. In particular, an exclusive 4PL framework to create a *best of breed* setup has been proposed in a balanced approach.

4.3 Industry Case Study

The *Make-Shift* methodology to eliminate bias factor prior to DEA evaluation in SC environment has been illustrated in section 4.3.1. Multi-stage performance evaluation framework comprising of dynamic lag effects with output disposability relaxation has been demonstrated in section 4.3.2.

4.3.1 *Make-Shift* Methodology as a Pre-Requisite Setting for Further DEA Evaluation

The estimation of net dependence effect from supplier's perspective for a tiller and tractor manufacturing company has been demonstrated using Kraljic's matrix. The study considers 20 gears supplier signified as G01 to G20. With regard to other suppliers, the final results of *Make-Shift* methodology have been represented. The dependent and independent parameters for the modified Kraljic's matrix has been obtained from interaction parameters as reported in table 4.2 with respect to financial, strategic and cooperation value drivers. Specifically, the main aim of the selected value drivers looks at identification of *like-minded* trading partners for long-term 4PL setting. The dependent parameters from supplier's perspective considered for the study has been reported as follows:

1. Communication
2. Commitment
3. Reputation
4. Total Delivery Performance
5. Total Quality Performance
6. Trading Partner Production Capacity
7. Years in Relationship
8. Business Share in USD
9. Innovation Capability

Details of all the suppliers along with their past performance records have been collated to arrive at cumulative score. Specifically, estimation of cumulative score with regard to dependent parameters has been carried out for individual parameters as follows:

- **Parameters 1 to 3: Communication, Commitment and Reputation**

  Communication, Commitment and Reputation parameters have been captured through individual gears supplier monthly breakup of scheduled, received and accepted quantity respectively. These details have been collected from the master production list and analysed to understand the supply trend. For instance, scheduled quantity plot for gears supplier has been shown in fig. 4.15.

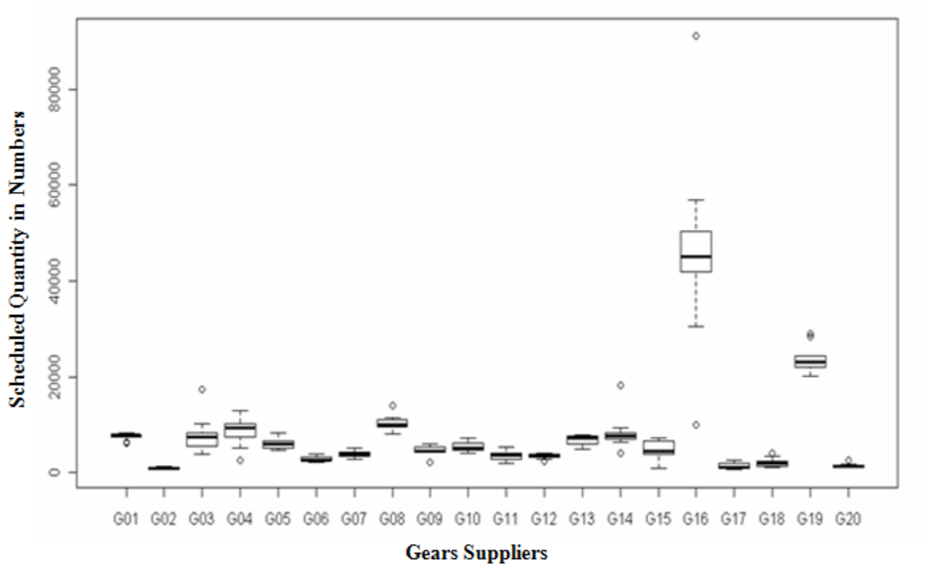


Figure 4. 15 Scheduled quantity distribution plot of gears supplier

  After consolidating all the suppliers' data, confidence interval and median statistics of individual gears supplier has been calculated. Based on the median values, ranking of individual supplier has been carried out in decreasing order. In case of tie situations, the subsequent rank has been eliminated. Similarly, the ranking for received (commitment) and accepted (reputation) quantity dependent parameters has been performed in decreasing order.

- **Parameter 4 and 5: Total Delivery and Quality Performance**

  TDP and TQP trend helps company to analyse the supplier performance with respect to delivery and quality. TDP is calculated using equation (4.13) and TQP is computed using expression (4.14). Based on the values, ranking of individual supplier has been carried out in decreasing order.

$$\text{TDP in \%} = \frac{\text{Total Received Quantity}}{\text{Total Scheduled Quantity}} * 100 \qquad \ldots\ldots\ldots (4.13)$$

$$\text{TQP in \%} = \frac{\text{Total Accepted Quantity}}{\text{Total Received Quantity}} * 100 \qquad \ldots\ldots\ldots (4.14)$$

- **Parameter 6: Trading Partner Production Capacity**

  Based on the production capacity allocated to the buying organisation, ranking of individual supplier has been carried out in increasing order. The analogy for this ranking order presumes that supplier with fewer customers imply longer relationship with the buying organisation.
- **Parameters 7 to 9: Business Share, Relationship and Innovation Capability**

  Business share is derived from the value of financial transaction between individual supplier and company in USD. Here, ranking has been conducted in decreasing order based on the financial value. Relationship in years measure the duration of business transaction and innovation capability deals with the product mix variety between individual supplier and company. Finally, relationship in years and type of components ranking has been carried out in decreasing order.

Conversely, criticality of developing the source has been scaled component-wise in the form of ‘A’, ‘B’ and ‘C’ category in numbers with respect to individual supplier. This has been carried out by consolidating master supplier list along with component details. Consequently, brainstorming activity with the respective buyer’s team of the company has been conducted for component-wise scaling. In addition, assistance of two management trainees has been utilised for completing this process. In the next stage, the consolidated cumulative score and criticality of sourcing rank of gears supplier has been reported in table 4.4.

Table 4. 4 Consolidated ranking based on MCDM framework

		Dependent Parameters										Independent Parameter
	Criteria	Scheduled Qty.	Received Qty.	Accepted Qty.	Total Quality Performance	Total Delivery Performance	No. of Main Customers	Relation with the Company	Components Supplying in Nos.	Business Share with the Company	Cumulative Score	Criticality of Component Sourcing
Sl. No.	**Weight**	1	1	1	1	1	1	1	1	1		
1	**G01**	5	5	4	2	4	13	2	7	6	**48**	**17**
2	**G02**	20	20	20	5	17	1	7	5	20	**115**	**6**
3	**G03**	7	8	6	1	13	20	4	13	2	**74**	**2**
4	**G04**	4	4	7	18	14	13	15	20	19	**114**	**9**
5	**G05**	9	9	9	12	20	1	2	5	14	**81**	**10**
6	**G06**	16	16	16	20	2	4	17	16	11	**118**	**8**
7	**G07**	13	13	14	9	1	10	10	15	10	**95**	**7**
8	**G08**	3	3	3	14	11	10	13	3	4	**64**	**4**
9	**G09**	12	12	11	8	7	4	9	18	13	**94**	**15**
10	**G10**	10	10	12	15	11	8	10	8	8	**92**	**11**
11	**G11**	14	15	15	11	9	10	5	11	16	**106**	**18**
12	**G12**	15	14	13	6	6	8	1	10	15	**88**	**13**
13	**G13**	8	7	8	16	5	1	7	11	5	**68**	**14**
14	**G14**	6	6	5	7	19	13	16	9	7	**88**	**12**
15	**G15**	11	11	10	10	10	17	20	2	16	**107**	**1**
16	**G16**	1	1	1	3	8	19	12	4	3	**52**	**3**
17	**G17**	19	19	19	19	15	13	19	18	18	**159**	**15**
18	**G18**	17	17	17	17	18	17	13	13	9	**138**	**19**
19	**G19**	2	2	2	13	3	4	5	1	1	**33**	**5**
20	**G20**	18	18	18	4	16	4	18	16	12	**124**	**20**

From the cumulative score column, lesser the score infers higher the value of supplier. Similarly, cumulative score and criticality of sourcing rank for all categories of supplier (Castings, Sheet Metal, and Turned and Machined components) has been calculated accordingly.

In the next step, categorisation of suppliers has been carried out using modified Kraljic's matrix with criticality of sourcing rank on the X-axis and cumulative score on the Y-axis. Finally, the clustering of trading partners has been carried out through criticality of sourcing median and cumulative score median. Based on the results secured, the individual suppliers have been plotted in the modified Kraljic's matrix accordingly. In what follows, results from the *Make-Shift* methodology for 20 gears supplier have been depicted as follows:

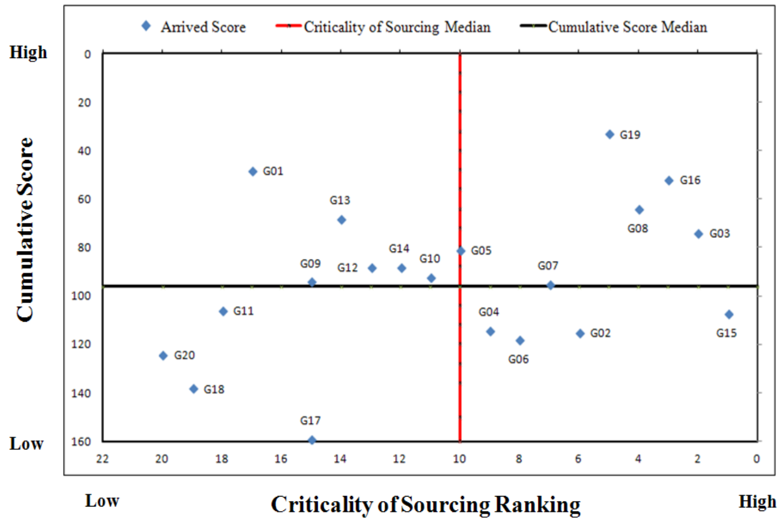


Figure 4. 16 Cluster analysis of gear suppliers

Results showed six suppliers each have been clustered into critical and security quadrants. In addition, four suppliers have been clustered into acquisition and profit quadrants respectively. Suppliers G11, G17, G18 and G20 under acquisition cluster have been considered as low profile suppliers, where, the buying organisation need not develop potential relationship. Suppliers G02, G04, G06 and G15 under profit cluster have one-sided relationship, where in, supplier depends more on the buying organisation. Similarly, suppliers G01, G09, G10, G12, G13 and G14 under security cluster have low profile, but, the client organisation depends more on the supplier. Lastly, the suppliers G03, G05, G07, G08, G16, and G19 under critical cluster have high potential for strong relationship, wherein, both the parties matter to each other. Similar procedure has been carried out for castings, sheet metal, and turned and machined suppliers as shown in Appendix-B.2. The validation of the proposed *Make-Shift* methodology has been reported in section 4.3.3 which yielded strong positive relationship with $\rho \geq 0.7$.

In order to address special cases like border-line issues, *k*-mediod clustering has been applied to handle operational issues for grouping. Figure 4.17 shows the gear suppliers with border-line issues raising a conflict of grouping. For instance, G07 supplier resides on the border-line (red circle) of critical and profit cluster. In order to address this issue, Euclidean distance between cluster-specific *best peer* DMUs (green circle) and border-line supplier has been calculated using equation 4.2. In this case, the *best peer* DMUs from critical and profit cluster has been G03 and G15 supplier respectively.

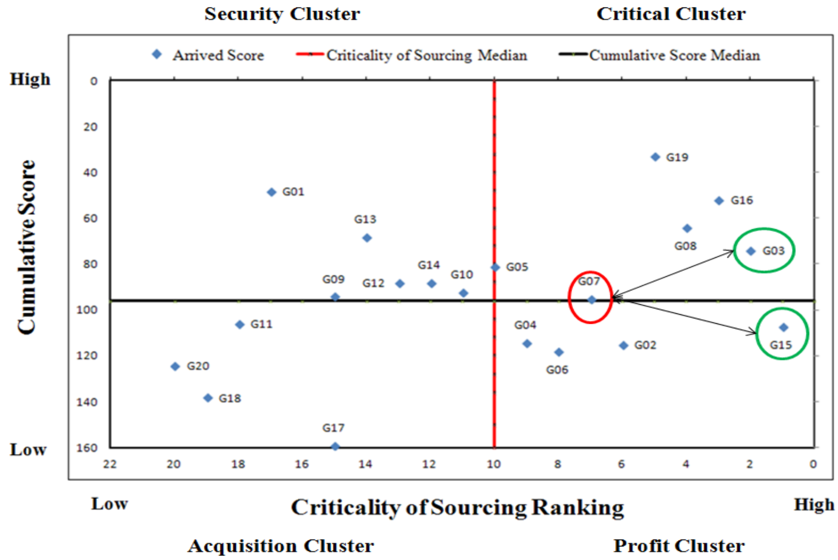


Figure 4. 17 Conflict between clusters for border-line suppliers

Based on the distance measure, it has been observed that G07 supplier has the minimum score with G03 supplier which is the *best peer* DMU in critical cluster. Therefore, G07 supplier belongs to the critical cluster as shown in fig. 4.18 and the categorisation operation can be carried out accordingly.

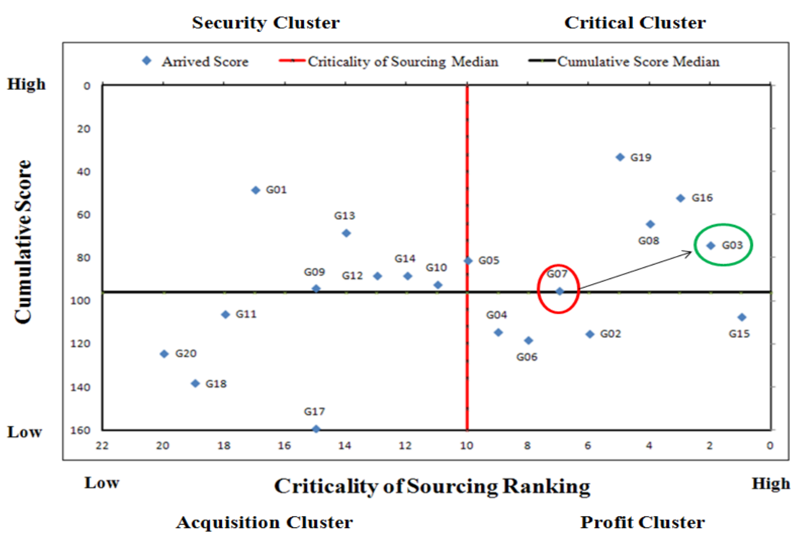


Figure 4. 18 Operationalising procedure for border-line suppliers

Consequently, an attempt to derive weights objectively for the multi-criteria dependent parameters in the proposed *Make-Shift* methodology is presented using a cooperative approach. In this study, the considered nine dependent parameters in table 4.2 has been represented as ‘a’ to ‘i' respectively. Initially, the ranking score matrix $\mathbf{R_s}$ has been normalised and characteristic function for all the coalition $c(S_c)$ has been estimated using equation 4.6. The characteristic function of the individual parameter in the coalition {abcdefghi} has been depicted in table 4.5.

Table 4. 5 Characteristic function of the coalition {abcdefghi}

Sl. No.	$c(S_c)$	Value
1	$c(\{a\})$	0.1343
2	$c(\{ab\})$	0.2464
3	$c(\{abc\})$	0.3623
4	$c(\{abcd\})$	0.4677
5	$c(\{abcde\})$	0.5915
6	$c(\{abcdef\})$	0.7015
7	$c(\{abcdefg\})$	0.8060
8	$c(\{abcdefgh\})$	0.9118
9	$c(\{abcdefghi\})$	1.0000

By virtue of this, individual contribution of the dependent parameters has been estimated through decomposition of coalition combinations. For instance, individual contribution of the coalition {abcdefghi} has been reported in the table 4.6.

Table 4. 6 Individual contribution of the coalition

Sl. No.	Coalition	Individual Contribution	Weights
1	$c(\{abcdefghi\}) - c(\{abcdefgh\})$	i	0.0882
2	$c(\{abcdefgh\}) - c(\{abcdefg\})$	h	0.1058
3	$c(\{abcdefg\}) - c(\{abcdef\})$	g	0.1045
4	$c(\{abcdef\}) - c(\{abcde\})$	f	0.1099
5	$c(\{abcde\}) - c(\{abcd\})$	e	0.1238
6	$c(\{abcd\}) - c(\{abc\})$	d	0.1054
7	$c(\{abc\}) - c(\{ab\})$	c	0.1159
8	$c(\{ab\}) - c(\{a\})$	b	0.1120
9	$c(\{a\}) - c(\{\phi\})$	a	0.1343
Total Sum			1.0000

In the similar way, the individual contribution for all the ordering combinations has been calculated. Lastly, *Shapley value* function is calculated through an average function and weights for all the dependent parameters have been attained in a consensual approach as shown in table 4.7.

Table 4. 7 Shapley value calculations

Sl. No.	Coalition	a	b	c	d	e	f	g	h	i	Sum
1	a←b←c←d←e←f←g←h←i	0.1343	0.1120	0.1159	0.1054	0.1238	0.1099	0.1045	0.1058	0.0882	1
2	b←c←d←e←f←g←h←i←a	0.0833	0.1304	0.1159	0.1147	0.1178	0.1032	0.1123	0.1151	0.1072	1
3	c←d←e←f←g←h←i←a←b	0.0975	0.0882	0.1176	0.1218	0.1268	0.1044	0.1167	0.1270	0.1000	1
4	d←e←f←g←h←i←a←b←c	0.1092	0.0883	0.0882	0.1343	0.1192	0.1289	0.1097	0.1269	0.0953	1
5	e←f←g←h←i←a←b←c←d	0.1150	0.0941	0.0986	0.1014	0.1324	0.1323	0.1029	0.1245	0.0988	1
6	f←g←h←i←a←b←c←d←e	0.1120	0.1041	0.0980	0.1129	0.0968	0.1364	0.1176	0.1270	0.0952	1
7	g←h←i←a←b←c←d←e←f	0.1067	0.1054	0.1120	0.1129	0.1177	0.0882	0.1343	0.1197	0.1031	1
8	h←i←a←b←c←d←e←f←g	0.1192	0.1091	0.1159	0.1015	0.1159	0.1014	0.0870	0.1304	0.1196	1
9	i←a←b←c←d←e←f←g←h	0.1214	0.1038	0.1110	0.1267	0.1268	0.0986	0.0986	0.0845	0.1286	1
Shapley Value (Average Value of Weights)		**0.1110**	**0.1039**	**0.1081**	**0.1146**	**0.1197**	**0.1115**	**0.1093**	**0.1179**	**0.1040**	1

Based on the attained weights, further analysis can be conducted. However, this thesis assumes the philosophy of having equal weights for all the dependent parameters. In summary, the proposed methodology can be a readily accepted means for elimination of bias factor prior to DEA evaluation in SC environment. Likewise, the coordinator of transaction centre can develop appropriate relationship to enhance the performance of trading partners for 4PL operations.

4.3.2 Efficiency Measurement using the Proposed Multi-Stage Performance Evaluation Framework

The input and output parameters for suppliers and LSPs have been attained from the transaction parameters as reported in table 4.3 from buying organisation's view point. Analysis of suppliers has been carried out considering following input-output parameters from operations perspective as shown below:

Table 4. 8 Input and output parameters for supplier DMUs

Sl. No.	Input Parameters	Output Parameters
1.	Quantity Scheduled in Numbers	Quantity Accepted in Numbers
2.	Main Customers to the Supplier in Numbers	Revenue Spend in USD
3.	--	Types of Components Supply in Numbers

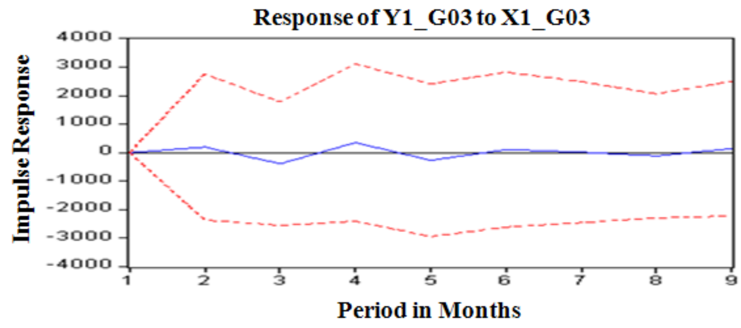
For illustration, gears supplier (Gi) has been considered and similar analysis has been conducted to other category of suppliers (Ci, Si and Mi). Also, consolidated results for all categories of supplier have been signified. Mathematical formulation for Gi under c-RTS and v-RTS characterisation with regard to stage-1 condition has been executed. Moving forward, '*main customers to the supplier'* input has been viewed as non-controllable input in stage 2. In stage 3, categorisation of Gi has been considered from the proposed *Make-Shift* methodology results. In continuation, stage 4 condition combines non-controllable and categorical model with input parameter '*main customers to the supplier*' not considered along with categorical formulation. Lastly, stage 5 extends the static DEA model to dynamic considerations by estimating individual lag parameters for evaluating performance effectively.

In order to look at dynamic effects, time series input and outputs from stage 4 have been considered to check for non-stationary condition as reported in section 4.3.3. Further, econometrics VAR model has been utilised to estimate inter-temporal effects between inputs-outputs in the form of lag parameters. From the results secured, DEA analysis has been carried out to evaluate dynamic performance. For the study, only outputs have been considered due to output oriented approach with two month lag period. Further, dynamic output-1($\tilde{Y}_{1p}$) and dynamic output-2 ($\tilde{Y}_{2p}$) has been represented in equation (4.15) and (4.16) respectively.

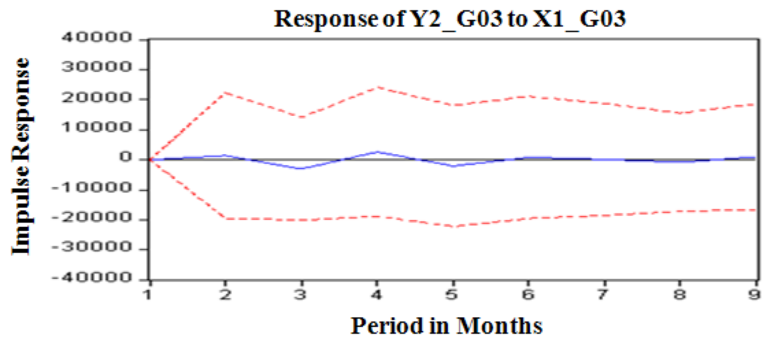
$$\tilde{Y}_{1p} = a_1 + \sum_{j=1}^{n} b_j Y_{1p-j} + \sum_{j=1}^{n} \beta_j X_{1p-j} + u_{1p} \quad \text{………………..} \; (4.15)$$

$$\tilde{Y}_{2p} = a_2 + \sum_{j=1}^{n} b_j Y_{2p-j} + \sum_{j=1}^{n} \beta_j X_{1p-j} + u_{2p} \quad \text{………………..} \; (4.16)$$

Figure 4.19 shows the output responses of G03 supplier after applying positive shock of one standard deviation for nine month time period.



Impulse response of Y1_G03 model



Impulse response of Y2_G03 model

Figure 4. 19 Output response of the dependent variable after applying shock characteristics

For example, the two dynamic outputs of VAR estimation model for G03 supplier with two lags and period five has been represented in expressions (4.17) and (4.18) respectively.

(Output-1, $\tilde{Y}_1$)

$$\tilde{Y}_{15} = 13367.34 - 1.4031Y_{14} + 0.6843Y_{13} + 0.5494X_{14} - 0.6710X_{13} + u_{15} \quad \ldots\ldots\ldots\ldots (4.17)$$

(Output-2, $\tilde{Y}_2$)

$$\tilde{Y}_{25} = 111961.70 - 1.3Y_{14} + 0.6913Y_{13} + 4.0106X_{14} - 5.7773X_{13} + u_{25} \quad \ldots\ldots\ldots\ldots (4.18)$$

After substituting corresponding values to the variables, static and dynamic output comparison has been shown as follows:

Table 4. 9 Static and dynamic output comparison for individual period of G03

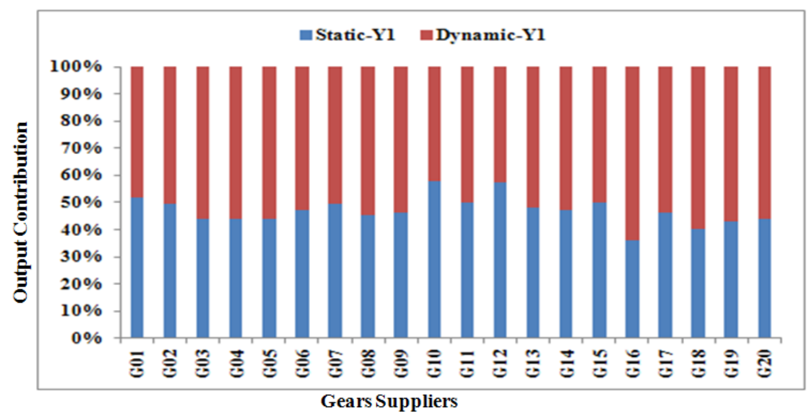
Sl. No.	Parameter (For, k = 2, p = 5)	Static-Y_i	Dynamic-$\tilde{Y}_i$
1	Output – 1 (Quantity Accepted in Numbers)	3834	3546
2	Output – 2 (Revenue Spend in USD)	32344	30339

Similarly, considering nine month period values individually; the aggregate values of G03 supplier have been depicted below:

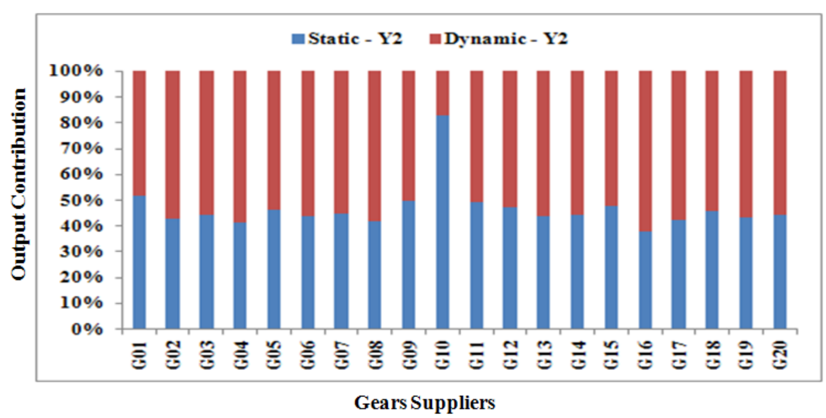
Table 4. 10 Static and dynamic output comparison for consolidated period of G03

Sl. No.	Parameter	Static-Y_i	Dynamic-$\tilde{Y}_i$
1	Output – 1 (Quantity Accepted in Numbers)	64,299	81,610
2	Output – 2 (Revenue Spend in USD)	5,42,601	6,86,688

In summary, the contribution of static and dynamic output datasets for all the Gi have been reported in figure 4.20. Therefore, output disposability relaxation has been demonstrated with variable lag effects which can have positive, neutral or negative impact on the subsequent chain partner.



Output-1 comparison of gear suppliers



Output-2 comparison of gear suppliers

Figure 4. 20 Static and dynamic output comparison

Moreover, summary of the stage-wise results has been reported in table 4.11 and 4.12 under both characterisations.

Table 4. 11 Summary of results for gears supplier under c-RTS

Sl. No.	Description	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
1	Number of DMUs	20	20	20	20	20
2	Number of Efficient DMUs	7	9	11	9	7
3	Average Efficiency Scores	0.9197	0.9423	0.9432	0.9319	0.8690
4	Standard Deviation	0.0883	0.0825	0.0776	0.0769	0.1438
5	Maximum Score	1	1	1	1	1
6	Minimum Score	0.7499	0.7499	0.7611	0.7559	0.5622

Table 4. 12 Summary of results for gears supplier under v-RTS

Sl. No.	Description	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
1	Number of DMUs	20	20	20	20	20
2	Number of Efficient DMUs	10	10	13	12	9
3	Average Efficiency Scores	0.9383	0.9492	0.9626	0.9576	0.9134
4	Standard Deviation	0.0860	0.0830	0.0711	0.0699	0.1333
5	Maximum Score	1	1	1	1	1
6	Minimum Score	0.7499	0.7499	0.7615	0.7605	0.5859

To evaluate static and dynamic efficiency frontiers (stage 4 and 5), system efficiency model has been adopted (see Section 4.3.3). It has been observed that stage 5 system yielded better results than stage 4 with regard to number of efficient DMUs and average efficiency. Therefore, stage 5 has been considered as the final improvement of the proposed performance evaluation framework. In addition, stage-wise average efficiency scores of gears supplier has been reported in fig. 4.21. It has been observed that average efficiency varies as and when complexity conditions have been added under both RTS characterisations. Nonetheless, efficiency decrease in stage 5 has been due to the extension from static to dynamic model. Hence, static models over estimate the efficiency scores compared to dynamic evaluation.

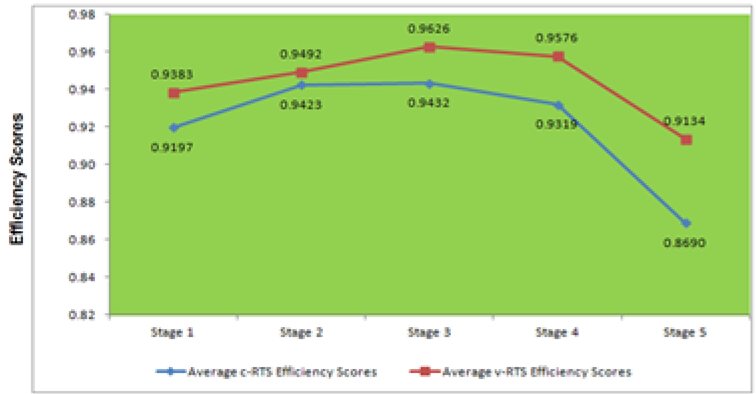


Figure 4. 21 Average efficiency scores comparison from the developed framework

Considering stage 5 results of gears supplier, the overall output projections summary have been shown in figure 4.22.

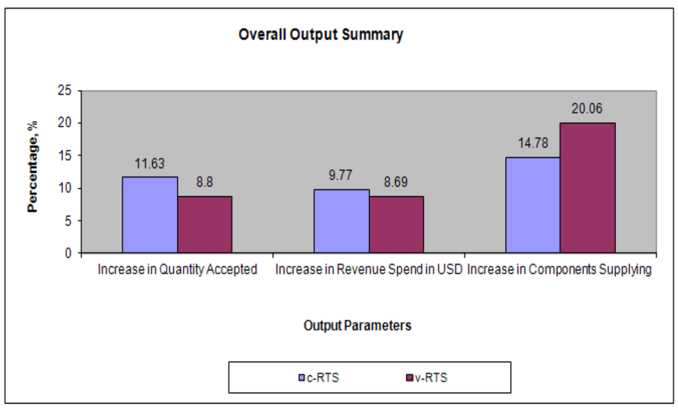


Figure 4. 22 Output summary projections under both RTS characterisation

Similarly, category wise average efficiency scores for both RTS characterisations have been depicted in figure 4.23.

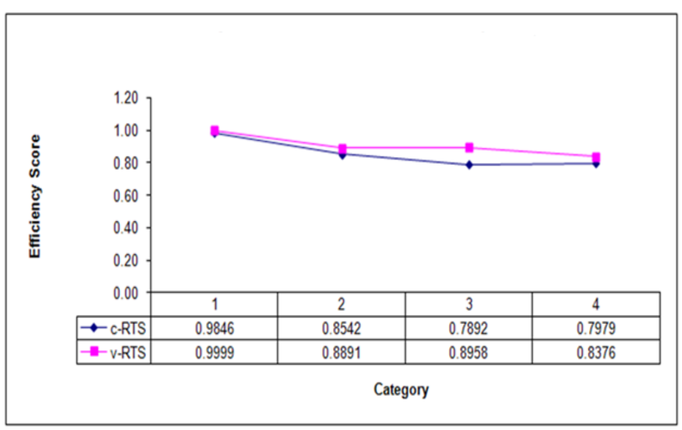


Figure 4. 23 Average efficiency details for both RTS characterisation category-wise

Also, projection details for individual DMU shows the possible target area with reference to different outputs in order to reach the efficiency frontier. It has been observed that the average efficiency score decreases with higher category of gears supplier. Summary of efficiency decomposition for gears supplier has been computed in table 4.13.

Table 4. 13 Decomposition of efficiency for gears supplier DMUs

Sl. No.	DMU	Global TE (θ_{CCR}^*)	Local Pure TE (θ_{BCC}^*)	SE	Source of Inefficiency
1	G03	1	1	1	Most productive scale size
2	G16	1	1	1	Most productive scale size
3	G08	1	1	1	Most productive scale size
4	G19	0.9964	1	0.9964	Disadvantageous working condition due to scale size
5	G07	0.9111	0.9999	0.9111	Inefficient operations, disadvantageous working condition due to scale size
6	G05	1	1	1	Most productive scale size
7	G10	0.7787	0.7944	0.9802	Inefficient operations, disadvantageous working condition due to scale size
8	G14	0.7509	0.7510	0.9999	Inefficient operations, disadvantageous working condition due to scale size
9	G12	1	1	1	Most productive scale size
10	G13	0.9703	0.9708	0.9995	Inefficient operations, disadvantageous working condition due to scale size
11	G09	0.7958	0.9892	0.8046	Inefficient operations, disadvantageous working condition due to scale size
12	G01	0.8293	0.8295	0.9997	Inefficient operations, disadvantageous working condition due to scale size
13	G15	0.6741	1	0.6741	Disadvantageous working condition due to scale size
14	G02	1	1	1	Most productive scale size
15	G06	0.9203	0.9973	0.9228	Inefficient operations, disadvantageous working condition due to scale size
16	G04	0.5622	0.5860	0.9595	Inefficient operations, disadvantageous working condition due to scale size
17	G17	0.6892	0.7651	0.9007	Inefficient operations, disadvantageous working condition due to scale size
18	G11	0.6070	0.6217	0.9765	Inefficient operations, disadvantageous working condition due to scale size
19	G18	0.8952	0.9636	0.9291	Inefficient operations, disadvantageous working condition due to scale size
20	G20	1	1	1	Most productive scale size
Avg. Efficiency		**0.8690**	**0.9134**	**0.9527**	

This table depicts SE details along with sources of inefficiency. Hence, the developed framework helps the coordinator to assimilate their efficiency score along with improvement directions. Similarly, DEA evaluation has been executed for all the categories of suppliers. Thus, the consolidated projection details of all supplier categories under both RTS characterisations have been depicted in figure 4.24 and 4.25 correspondingly.

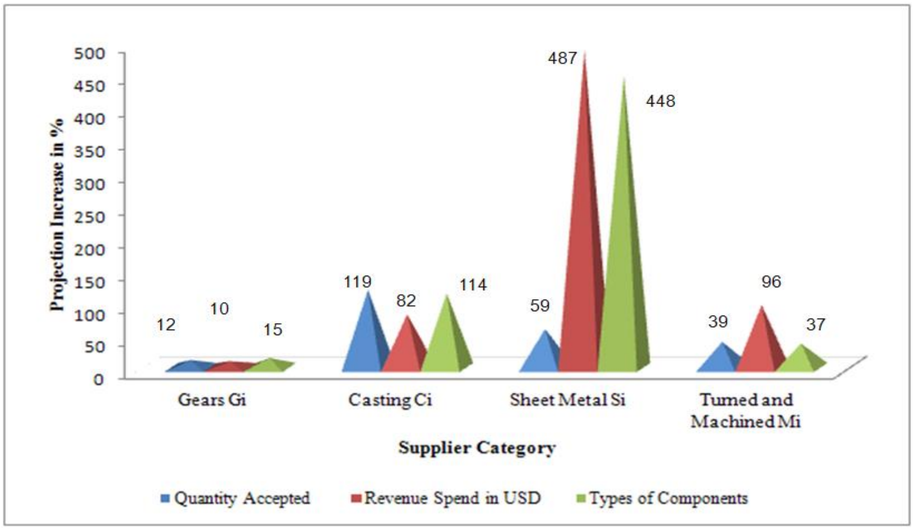


Figure 4. 24 Consolidated projections of all supplier categories under c-RTS

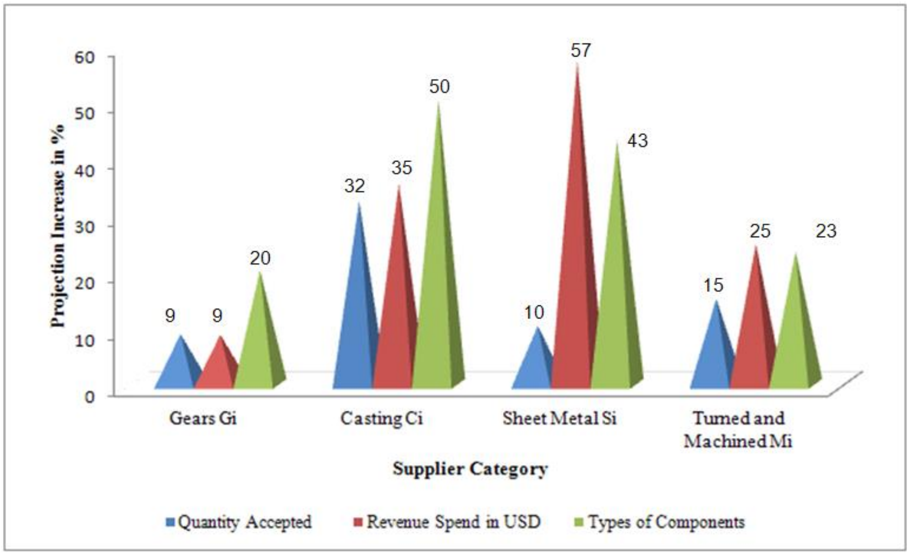


Figure 4. 25 Consolidated projections of all supplier categories under v-RTS

From the stage 5 results, tie-situation has been observed in the ranking of efficient DMUs. Thus, super efficiency DEA model has been used (expression 4.12). The final solution and ranking after applying super efficiency model under both RTS characterisation has been presented in the below table:

Table 4. 14 Ranking details after applying super efficiency model of gears supplier

		c-RTS		v-RTS	
Sl. No.	**DMU**	**Rank from Efficiency score**	**Rank from Super Efficiency score**	**Rank from Efficiency score**	**Rank from Super efficiency score**
1	G03	1	3	1	6
2	G16	1	2	1	1
3	G08	1	6	1	7
4	G19	8	8	1	2
5	G07	11	11	10	10
6	G05	1	5	1	4
7	G10	15	15	16	16
8	G14	16	16	18	18
9	G12	1	7	1	8
10	G13	9	9	13	13
11	G09	14	14	12	12
12	G01	13	13	15	15
13	G15	18	18	1	5
14	G02	1	1	1	8
15	G06	10	10	11	11
16	G04	20	20	20	20
17	G17	17	17	17	17
18	G11	19	19	19	19
19	G18	12	12	14	14
20	G20	1	4	3	3

In the similar way, analysis of LSPs using DEA has been carried out under dynamic consideration. For the study, 10 LSP DMUs have been selected based on the region-wise source of components. Lag parameters of LSPs have been estimated using VAR econometric model from the static dataset. Further, input and output parameters for the study have been considered from 4PL transaction centre perspective as shown in table 4.15. Nonetheless, the condition mentioned in expression (3.4) has been satisfied.

Table 4. 15 Input and output parameters for LSP DMUs

Sl. No.	Input Parameters	Output Parameters
1.	Consignment Order Frequency in Numbers	Weight Shipped in kg
2.	--	Revenue Spend in USD

To capture carry-over effect through dynamic output, proposed methodology in stage 5 has been applied for LSPs directly. Hence, the static output has been converted into dynamic output. Subsequently, output oriented DEA model under both characterisations has been applied for performance evaluation.

Figure 4.26 portrays the component sourcing details across India with state-wise component distribution for the selected tiller and tractor manufacturing company. But, Karnataka state percentage figure does not include the components sourcing from in and around Bangalore.

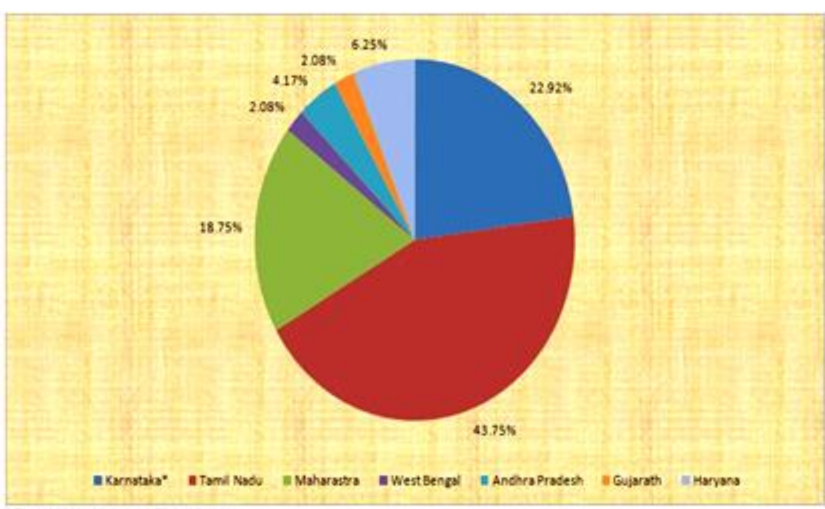


Figure 4. 26 State-wise component distribution in percentage

Based on regional services of LSPs, the sourcing regions have been divided into three clusters as reported in fig. 4.27. The cluster-1 consists of Tamil Nadu region; cluster-2 comprises of Belgaum and Kolhapur region, and cluster-3 deals with rest of India uncovered by the other two clusters. These cluster details have been captured under different categories in DEA formulation.

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Figure 4. 27 Details of clusters for LSP DMU analysis

In summary, category-wise average efficiency score of LSP DMUs under both RTS characterisations have been shown in fig. 4.28.

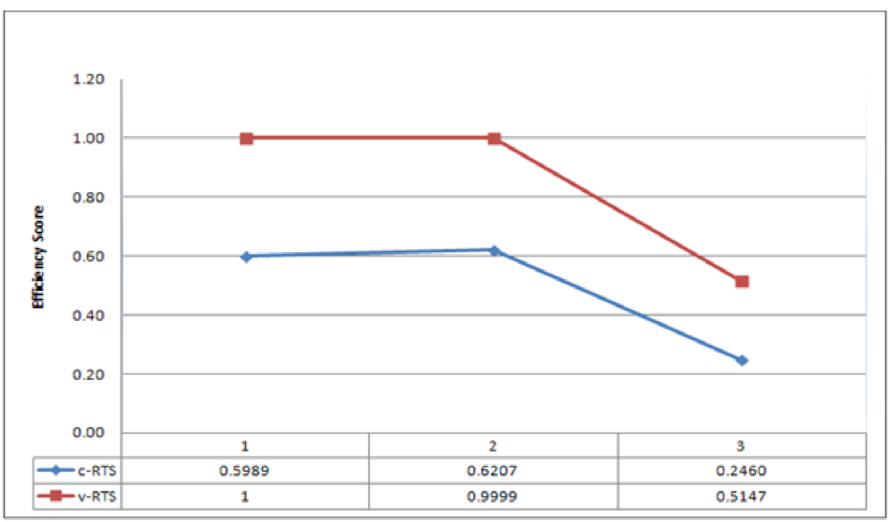


Figure 4. 28 Category-wise average efficiency scores of LSP DMUs

It has been observed that category-2 has the highest efficiency score under c-RTS characterisation. On the contrary, category-1 and 2 exhibit same average efficiency under v-RTS characterisation. Similarly, the consolidated projection details have been shown in figure 4.29.

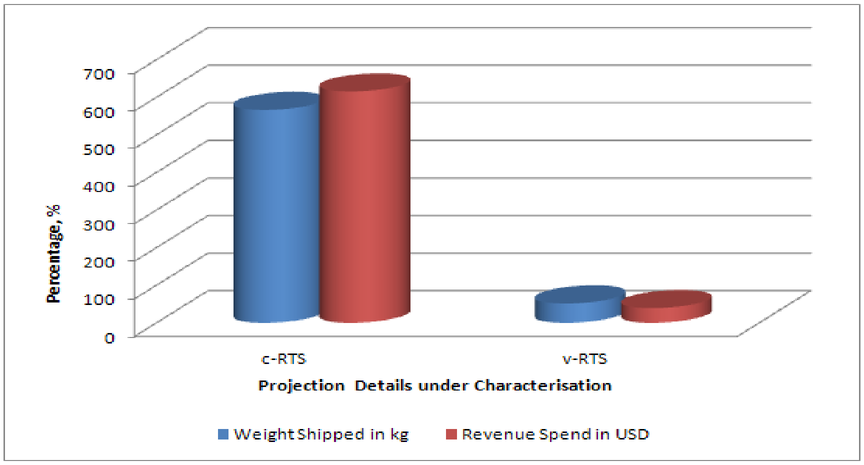


Figure 4. 29 Consolidated average projections of LSP DMUs

In the next step, SE for LSP DMUs has been calculated and collated in table 4.16 from expressions (3.7).

Table 4. 16 Decomposition of efficiency for LSP DMUs

Sl. No.	DMU	Global TE (θ_{CCR}^*)	Local Pure TE (θ_{BCC}^*)	SE	Source of Inefficiency
1	L01	0.1978	1	0.1978	Disadvantageous working condition due to scale size
2	L02	1	1	1	Most productive scale size
3	L03	0.4737	1	0.4737	Disadvantageous working condition due to scale size
4	L04	0.5244	1	0.5244	
5	L05	0.8642	1	0.8642	
6	L06	0.0456	0.9152	0.0498	Inefficient operations, disadvantageous working condition due to scale size
7	L07	0.1024	0.4810	0.2130	
8	L08	0.0658	0.1532	0.4298	
9	L09	0.0160	0.0240	0.6675	
10	L10	1	1	1	Most productive scale size
Average Efficiency		**0.4290**	**0.7573**	**0.5420**	

Consequently, super efficiency DEA model for LSPs have been applied to address tie-situation in the ranking of efficient DMUs. Super efficiency ranks for LSP DMUs under both characterisations have been collated in table 4.17.

Table 4. 17 Ranking details after applying super efficiency model of LSP DMUs

		c-RTS		v-RTS	
Sl. No.	DMU	Rank from Efficiency score	Rank from Super Efficiency score	Rank from Efficiency score	Rank from Super Efficiency score
1	L01	6	6	1	1
2	L02	1	1	1	4
3	L03	5	5	1	2
4	L04	4	4	6	6
5	L05	3	3	1	3
6	L06	9	9	7	7
7	L07	7	7	8	8
8	L08	8	8	9	9
9	L09	10	10	10	10
10	L10	1	2	1	4

4.3.3 Model Evaluation and Validation

Validation of the proposed *Make-Shift* methodology:

Like-minded group of gears supplier in different clusters has been validated using Spearman's rank correlation co-efficient test ρ to estimate strength of the relationship. This has been carried out by identifying the '*best peer*' supplier through criticality of sourcing rank as shown in fig. 4.30.

Security Cluster

	Cum. Score	Criticality Rank
G01	48	17
G13	68	14
G09	94	15
G12	88	13
G14	88	12
G10	92	11

Critical Cluster

	Cum. Score	Criticality Rank
G19	33	5
G16	52	3
G03	74	2
G08	64	4
G07	95	7
G05	81	10

Acquisition Cluster

	Cum. Score	Criticality Rank
G11	106	18
G17	159	15
G18	138	19
G20	124	20

Profit Cluster

	Cum. Score	Criticality Rank
G15	107	1
G02	115	6
G06	118	8
G04	114	9

Best Peer Supplier

Figure 4. 30 *Best Peer* supplier in individual clusters

Finally, ρ between the *peer* suppliers has yielded strong positive relationship in individual clusters. Once trading partner reaches the frontier in individual cluster, the DMU can be graduated to the next cluster for improvement.

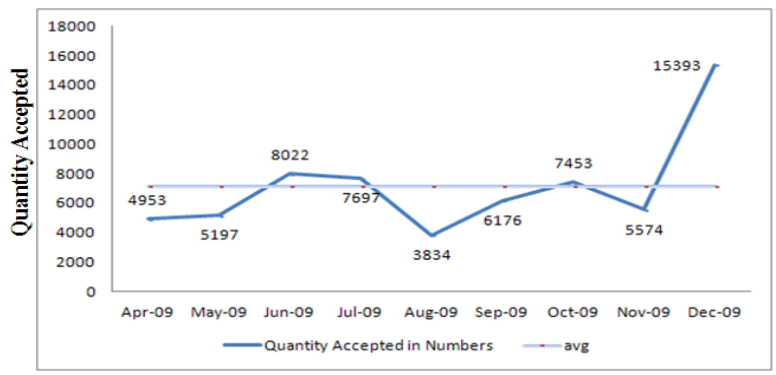
Test for non-stationarity condition of the dataset:

Validation tests of the time series datasets have been carried out using the following econometric tests:

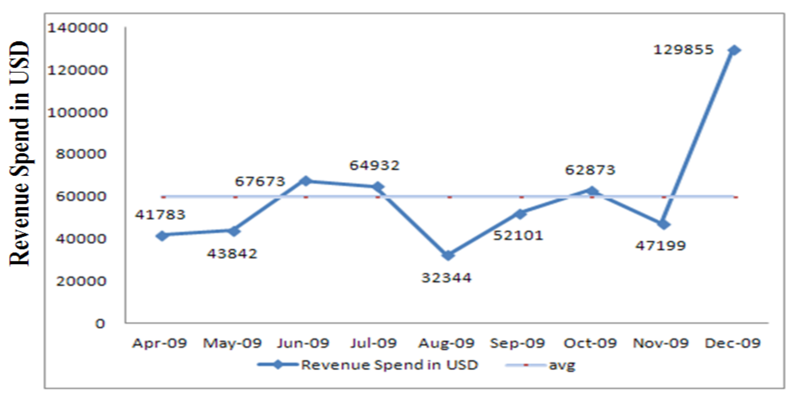
1. Graphical Analysis
2. Unit Root Test

1. Graphical Analysis:

Here, mean and variance has to be constant over time to satisfy stationary condition (Gujarati and Sangeetha, 2007). For demonstration, G03 supplier time series output has been considered for inference. Figure 4.31 shows the trend of output-1 (quantity accepted in numbers) and output-2 (revenue spend in USD) respectively.



Output 1



Output-2

Figure 4. 31 Output trend of G03 supplier

However, mean and variance appears to be different over time period in both the cases indicating non-stationarity of data. Further, the non-stationary time series can be transformed into stationary by taking the first difference Δ of the output Y_{ip} for the period-p corresponding to output i using expression (4.19).

$$\Delta Y_{ip} = (Y_{ip} - Y_{ip-1}) \qquad \ldots\ldots\ldots\ldots\ldots\ldots (4.19)$$

2. <u>Unit Root Test - ADF Test:</u>

The unit root random model with impulse response u_{ip} and ρ can be represented as follows:

$$Y_{ip} = \rho Y_{ip-1} + u_{ip} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (4.20)$$

Subtracting both sides by 'Y_{ip-1}' for the above equation

$$Y_{ip} - Y_{ip-1} = \rho Y_{ip-1} - Y_{ip-1} + u_{ip} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (4.21a)$$

$$Y_{ip} - Y_{ip-1} = (\rho - 1)\, Y_{ip-1} + u_{ip} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (4.21b)$$

$$\text{Therefore,} \quad \Delta Y_{ip} = \delta Y_{ip-1} + u_{ip}$$

$$\text{Here, } \delta = (\rho - 1)$$

The inference from the above can be interpreted as follows:

When δ = 0, then ρ = 1 indicating the presence of unit root. Hence, the time series data under consideration is non-stationary. Furthermore, ADF test has been used to estimate the coefficient of Y_{p-1}. But, application of ADF test involves several decisions in the form of '*no trend T - no intercept a_i*', 'a_i', and 'T-a_i' models. Considering all possibilities, ADF test has been represented as shown in equation (4.22), (4.23) and (4.24) respectively.

1. $\Delta Y_{ip} = \delta Y_{ip-1} + u_{ip}$ (no trend and no intercept) …………… (4.22)
2. $\Delta Y_{ip} = a_1 + \delta Y_{ip-1} + u_{ip}$ (intercept) …………… (4.23)
3. $\Delta Y_{ip} = a_1 + a_2 T + \delta Y_{ip-1} + u_{ip}$ (trend and intercept) …………… (4.24)

In addition, null H_0 and alternate H_1 hypothesis has been formulated to check for non-stationarity:

H_0: Output variable has the unit root (non-stationary)

H_1: Output variable do not have unit root (stationary)

However, G03 time series dataset has been looked for demonstration to check for non-stationarity. The output results have been shown in table 4.18 and 4.19 correspondingly at 5% significance level α.

Table 4. 18 Results of output-1 ADF test

Sl. No.	Condition	ADF Test Statistic (absolute)	Critical Test Statistic at α=5% (absolute)	Decision
1	No Trend and No Intercept	0.5494	1.9958	Accept H_0: The time series data has been non-stationary
2	Intercept	1.5374	3.3209	
3	Trend and Intercept	1.8301	4.2465	

Table 4. 19 Results of output-2 ADF test

Sl. No.	Condition	ADF Test Statistic (absolute)	Critical Test Statistic at α=5% (absolute)	Decision
1	No Trend and No Intercept	0.5537	1.9958	Accept H_0: The time series data has been non-stationary
2	Intercept	1.5229	3.3209	
3	Trend and Intercept	1.8193	4.2465	

The H_0 has been accepted which indicates the presence of unit root under different conditions. Thus, G03 time-series dataset under consideration has been considered as non-stationary. Here, the absolute value of ADF test statistic has been less than critical test statistic for other gears supplier. By virtue of this test, non-stationarity of the dataset has been validated. Hence, considering dynamic inter-relationships for performance evaluation ensures completeness in arriving at efficiency scores.

Static and dynamic DEA system comparison (Stage 4 and 5):

To evaluate extension from static to dynamic improvement, system efficiency model has been used for stage 4 and 5 to compare the efficient frontiers. The system efficiency model has been formulated in expression (4.25). This has been carried out by bringing all inputs ($\mathbf{X_4}$, $\mathbf{X_5}$) and outputs ($\mathbf{Y_4}$, $\mathbf{Y_5}$) to the efficiency frontier using projection details obtained from the DEA analysis. From this, η has been maximised using binary decision variable Z_i with lower L and upper U bound defined.

$$\begin{gathered} \text{Max. } \eta \\ \text{subject to constraints} \\ x_o \geq \mathbf{X}_4\boldsymbol{\mu}_4 + \mathbf{X}_5\boldsymbol{\mu}_5 \\ \eta y_o \leq \mathbf{Y}_4\boldsymbol{\mu}_4 + \mathbf{Y}_5\boldsymbol{\mu}_5 \\ LZ_4 \leq \mathbf{e}\boldsymbol{\mu} \leq UZ_4 \\ LZ_5 \leq \mathbf{e}\boldsymbol{\mu} \leq UZ_5 \\ Z_4 + Z_5 = 1 \qquad \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.25)} \\ \text{where } \boldsymbol{\mu}_4, \boldsymbol{\mu}_5 \geq 0 \text{ and } Z_4, Z_5 = \{0, 1\} \end{gathered}$$

Further, comparison of the DEA evaluation scores between stage 4 and 5 has been reported in table 4.20. Nonetheless, convexity condition (v-RTS) has not been considered between these two systems.

Table 4. 20 System comparison between stage 4 and 5 for gears supplier

Sl. No.	Description	System	
		Stage 4	Stage 5
1	Number of Efficient DMUs	1	6
2	Average Efficiency Score	0.6998	0.8630
3	Frequency of Reference to Other System	0	53
4	Standard Deviation	0.0976	0.1355
5	Maximum Efficiency Score	1	1
6	Minimum Efficiency Score	0.5491	0.5519

Output showed that stage 5 yields better results in terms of efficiency score and frequency of reference to other system compared to stage 4. Hence, dynamic performance evaluation in stage 5 estimates better operational efficiency compared to stage 4 in the proposed multi-stage framework. In parallel, Wilcoxon-Mann-Whitney rank sum test has been applied to validate the frontier shift between stage 4 and 5 systems. Based on the ranking of data, hypothesis test has been conducted to test whether systems belong to the same population or differ significantly. The test statistic for the rank sum test has been given in expression (4.26), where $T_{calculated}$ means calculated Wilcoxon-Mann-Whitney *T-statistic*, S means normal distribution statistic, A and B signifies number of stage 4 and 5 DMUs respectively. However, S has been calculated by adding stage 4 ranks after combining DMUs. In case of tie-situation, mid ranks has been considered. By virtue of this, S follows normal distribution assumption with mean '*A(A+B+1)/2*' and variance '*AB(A+B+1)12*'.

$$T_{calculated} = \frac{S - A(A+B+1)/2}{\sqrt{AB(A+B+1)/12}} \qquad \text{…………………} \ (4.26)$$

The $\mathbf{H_0}$ and $\mathbf{H_1}$ at $\alpha = 5\%$ is formulated as follows:

$\mathbf{H_0}$: *There is no significant frontier shift between stage 4 and stage 5 framework development and belong to the same population*

$\mathbf{H_1}$: *There is significant frontier shift between stage 4 and stage 5 framework development and do not belong to the same population*

Working principle of selecting the hypothesis using Wilcoxon-Mann-Whitney *T-statistics* has been depicted in Appendix B.3. Nevertheless, $\mathbf{H_0}$ has been accepted at $\alpha = 5\%$ with respect to $T_{critical}$. Therefore, improvements in stage 5 follow the same distribution of stage 4 with increased efficiency scores. Thus, stage 5 has been validated as the better performance evaluation system compared to stage 4. Hence, the proposed *Make-Shift* methodology and DEA performance evaluation framework have yielded better results.

4.4 Concluding Remarks and Summary

As 4PL comprises *best of breed* trading partners, exact operating procedure for creating this type of setup is not addressed in the logistics literature. Therefore, an exclusive 4PL performance measurement framework to develop *best of breed* DMU setup has been proposed in a balanced approach. Specifically, *best of breed* 4PL setup has been synthesised in two parts from trading partner and buying organisation perspective. The first part points to an important, yet much ignored issue, for applying DEA methodology in SC environment which comprises of heterogeneous DMUs with diverse goal and vision. To exploit DEA principles, attempt to reduce the size of the problem has been carried out by grouping *like-minded* trading partners in the SC network. Thus, the *Make-Shift* methodology to cluster heterogeneous DMUs into *like-minded* group prior to performance evaluation has been proposed by assimilating the net dependence effect. Here, interaction based parameters have been looked for estimating net dependence from trading partner perspective. In particular, the suggested methodology assists the coordinator of transaction centre to look at possible strength in the relationship before evaluating individual trading partners. Moreover, Kraljic's matrix with the proposed modifications can be used for clustering DMUs for further DEA evaluation. At the same time, *like-minded* group of trading partners in individual cluster yielded strong positive relationship. Based on the attained initial grouping, operational issues to deal with special cases have been addressed. In addition, the proposed *Make-Shift* methodology can be applied in other areas of DEA evaluation.

In the second part, the performance evaluation has been carried out using DEA from buying organisation perspective. After segregation of network members, new multi-stage performance evaluation framework has been developed under static and dynamic consideration by combining DEA and econometric models. Specifically, an integrated performance measure has been formulated exploring critical input-output parameters wherein the resultant framework can be generalised to an industry application. Here, the transaction based parameters have been looked for performance evaluation of trading partners from buying organisation perspective. The proposed framework identifies exact area of improvement directions for individual DMUs in the form of projections. These projected evaluation scores can be viewed as rationale to integrate trading partners for sustaining the post-merger effects in the 4PL transaction centre. Under static consideration, mathematical formulation has been carried out with respect to discretionary, non-discretionary and categorical conditions. In dynamic consideration, the intended framework relaxes output disposability assumption for lag parameters to mimic actual situation which can have positive, neutral or negative impact on their subsequent chain partner. Besides, it has been observed that static evaluation overestimates the efficiency score compared to dynamic consideration leading to bias and rank reversals. Further, the intended framework makes the model pragmatic by helping the coordinator to synthesise performance evaluation models. In summary, a pre-requisite setting for grouping *like-minded* DMUs has been carried out from trading partner's perspective and performance evaluation has been performed from buying organisation's perspective.

For demonstration, the heterogeneous gears supplier has been utilised to categorise into *like-minded* groups for further DEA evaluation. Results showed six suppliers clustered into critical and security quadrants; four suppliers clustered into acquisition and profit quadrants correspondingly. Accordingly, the supplier perception towards the company has been captured and the relationship with each supplier has been mapped. For instance, suppliers G03, G05, G07, G08, G16, and G19 under critical cluster imply high potential for strong relationship between the buying organisation and the supplier. Finally, the viability of the results has been validated for individual cluster with *'best peer'* supplier. The word *'best'* means supplier with highest criticality of sourcing rank in the respective cluster. Following categorisation from the *Make-Shift* methodology, the developed performance evaluation framework has been applied to gears supplier in five stages under both RTS with two inputs and three outputs. Assessment of suppliers from stage 1 to 4 has been carried out under static consideration with reference to basic output oriented DEA models. In stage 5, the static DEA model has been extended to dynamic considerations by estimating inter-temporal effects between input-outputs with disposability relaxations. Results revealed that static evaluation overestimates dynamic consideration by 4% to 5%. In addition, the proposed dynamic evaluation system yielded better DEA results with increase in number of efficient DMUs, average efficiency (~23%) and standard deviation (~38%) compared to static model. Furthermore, increase in standard deviation between trading partners infers that the lag parameters play an important role in performance evaluation. Similar procedure has been performed for all categories of suppliers along with LSPs. In principle, the suggested framework demonstrates better way of discrimination among the trading partners and can be adapted to other disciplines in the form of multi-stage performance evaluation. By virtue of this, the 4PL framework to create a *best of breed* trading partners for cross-segment integration has been presented. In the next chapter, cross-segment integration framework for the 4PL transaction centre has been proposed, implemented, evaluated and validated.

CHAPTER 5: INTEGRATION OF TRADING PARTNERS IN 4PL TRANSACTION CENTRE

5.1 Introduction

5.1.1 Brief about Supply Chain Integration (SCI)

One of the research areas which has drawn extensive attention is SCI to cope up with shorter product life cycle (Chu *et al.,* 2004). SCI combines relationship, operations, functions and business processes to manage intra and inter-organisational coordination (Ballou, 2007; Kotzab *et al.,* 2007). SCI can be achieved by focusing on key operational processes (Schmoltzi and Wallenburg, 2011; Mortensen and Lemoine, 2008) in an incremental way to achieve competitiveness (Aryee and Naim, 2008). Mortensen and Lemoine (2008) found that client organisations are not willing to depend more on third-party service providers. Instead, they are looking for the integration options in a *win-win* situation through frequent interactions. However, there is lack of comprehension on integration structure in the SC literature.

Zhao *et al.* (2011) presented a SCI framework considering the influencing factors, development activities along with methods available in the integration domain as depicted in fig. 5.1. The first requirement for conducting SCI relates to comprehensively identifying right set of trading partners for achieving common goal. Moreover, all the trading partners must be aware of influencing factors for SCI along with its driving and inhibiting parameters. In the next level, developments in SCI area have to be reviewed from R&D perspective along with industrial scenario. While R&D perspective looks at theoretical advancement, industrial development addresses implementation challenges foreseen during the integration process. By virtue of this, SC coordinator examines the latest trends and future directions in SCI domain. Based on the accumulated knowledge, exclusive approaches or methods can be developed for the integration process with respect to strategic, tactical and operational levels. In principle, a concrete way of integration theory development can be examined in the SC literature which is currently limited. Bottom-line, SCI looks for various approaches to add maximum value to the buying organisation (Zhao *et al.,* 2011). Furthermore, researchers in SCM domain unanimously agree that benefits accrue through integration of business processes for all the stake holders (Kotzab *et al.,* 2011; Zhao *et al.,* 2011).

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Figure 1: Scope of this Research – Q1, Q2 and Q3

Figure 5. 1 SCI framework

Source: Zhao et al. (2011)

However, this belief lacks theoretical foundation as it is based on subjective evidence (Kotzab *et al.*, 2011). Hence, an exclusive integration model is warranted while addressing implementation challenges and operational issues in the integration process. Besides, the developed frameworks have to support all the network members for long-term strategic planning (Routroy and Pradhan, 2013).

Organisations looking for SCI have considered 4PL as an interface between buying organisation and third-party service providers (Kutlu, 2007; Naesens *et al.*, 2007). Globalisation, better profits and single point of contact helps the client organisation to focus on their core competencies and this is deemed as one of the key motives for utilising 4PL (Kutlu, 2007). Moreover, SCI enables well-coordinated material flow from supplier's supplier to customer's customer (Yin and Khoo, 2007). In addition, Fabbe-Costes and Jahre (2007) have reported that the practical implementation of SCI is more challenging compared to theoretical proposition. Thus, adaptation and standardisation of the integration process is important for 4PL operations to reduce partnership risks (Knoppen and Christiaanse, 2007) in the SC network. On the contrary, cross-segment integration of different categories of trading partners can be successful by managing relationships which comprises of trust and dependence. In general, dependence is directly proportional to trust (Ireland and Webb, 2007). Here, cross-segment integration means merging different category of trading partners (For Ex: suppliers and LSPs) to achieve common goal (Anderssen *et al.*, 2010) by coordinating processes and systems (Wieland and Wallenburg, 2013). For instance, gear suppliers and LSPs can be combined in the form of a merger to ensure continuous supply of gears to the company from a particular geographical region. Further, the collaborative performance metrics are required for verifying the merger gain with respect to the integration goal (Simatupang *et al.*, 2004). Taking cue from this, an exclusive 4PL transaction centre model that can perform cross-segment integration comprehensively by combining competencies of different categories of trading partners is proposed. Besides, transaction centre in the 4PL framework provides a neutral platform for cross-segment integration and its working principle is reported in section 4.1. In summary, positive synergy from the cross-segment merger motivates the trading partners to pursue integration. However, exact operating framework for conducting cross-segment integration is not available in 4PL literature. This chapter addresses this gap and contributes to the theoretical advancement in this domain. In the next section, critique on challenges of cross-segment integration is reported with special reference to 4PL transaction centre.

5.1.2 Cross-segment Integration Challenges in 4PL Transaction Centre

4PL with the transaction centre approach is viewed as appropriate whenever individual transaction costs for a particular process is high (Bourlakis and Bourlakis, 2005). In general, cross-segment integration process focuses on buying organisation's requirement in alignment with their corporate strategy. However, understanding the challenges in implementation role of the integration process can be achieved through focusing on specific perspective of the problem statement (Yao, 2010). For this reason, the current research focuses on operation's perspective of cross-segment integration considering different categories of trading partners to evaluate merger efficiency. However, there is lack of evidence in the relationship between cross-segment integration and trading partner performance (Furlan *et al.*, 2006; Wu and Barnes, 2012). Figure

5.2 shows the relationship between integration and performance of trading partners which in-turn contributes to the enhancement of client organisation's competitiveness.

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Figure 5. 2 Framework to inter-link performance and integration

Source: Furlan et al. (2006)

The above conceptual framework highlights the mandate for integration of trading partners in SC network leveraging improvement in individual performance. By virtue of this improvement, the competitiveness of network members' and financial performance increases. Hence, there is a need to empirically examine the relationship between performance of the individual trading partner and the integration process (Fabbe-Costes and Jahre, 2008).

Hingley *et al.* (2011) investigated benefits and barriers of utilising 4PL for promoting cross-segment integration with special reference to transaction centre operations. Moreover, it becomes mandatory to analyse transaction cost of coordination in a 4PL transaction centre. The transaction cost includes cost of gathering data, contractual agreement and process monitoring cost. In general, transaction cost can be further classified into coordination cost and transaction risk. Here, coordination cost deals with direct cost of the operation (Spekman *et al.*, 1998). Further, transactional exchanges are suitable during constant demand and minimal product variation (Hingley *et al.*, 2011). However, there is no common understanding and synchronous view in the literature with regard to cross-segment integration of trading partner (Leeuw and Fransoo, 2009; Hingley *et al.*, 2011; Zhao *et al.*, 2011). Due to lack of empirical models on cross-segment integration, Muller and Aust (2011) called for portraying accurate findings with respect to a particular industry in order to promote broad-industry standards. Building this type of broad industry standards require long-term strategic partnership along with trust, moral ethics and minimal scope for opportunism across the different categories of trading partners (Zineldin and Bredenlow, 2003). In parallel, Visser (2007) and Yao (2010) reported that information sharing between trading partners facilitates cross-segment integration by enhancing collaborative partnerships. In summary, this type of cross-segment integration looks for reduction in operations cost to all the stakeholders by leveraging SC value (Chicksand *et al.*, 2012) along with productivity enhancement. Ogulin *et al.* (2012) found that matching capabilities and resources of the network members for the specific target market helps to coordinate 4PL activities. Singh (2013) called for identification and implementation of the best practices for cross-segment integration to improve coordination process in the 4PL network. Besides, selection of best practices deal with factors like business environment, product characteristic and company goal. In principle, integration of different categories of trading partners is considered as one of the competitive strategies for global companies (Brekalo *et al.*, 2013). Thus, cross-segment integration requires collaborative planning and sharing of resources for successful operations at different time and space (Kauppi, 2013). On the other hand, 70 to 80 per cent of value creation in the SC is through different category of network members (Harrison and van Hoek, 2008). Hence, modelling a 4PL transaction centre which integrates cross-segment trading partners for providing optimised mergers is warranted and signifies theoretical advancement in logistics research. Review of integration frameworks with respect to 4PL transaction centre are discussed in section 2.4.

This research study provides operating standards for cross-segment integration in the 4PL transaction centre. By virtue of the created platform, different categories of trading partners are pooled for long-term partnership to improve SC profitability (Ireland and Bruce, 2000). In this chapter, DMUs are mergers of suppliers and LSPs in the tiller and tractor manufacturing company. The main aim of this research deals with the implementation procedure for conducting cross-segment integration in the transaction centre for selecting the optimised merger. Moreover, organisations look for mergers in order to become a global company for conducting business activities in foreign markets (Kumar and Bansal, 2008). The subsequent section deals with review on quantifying merger gains.

5.1.3 Cross-segment Merger Efficiency

The merger gains are analysed with respect to cost parameter as per the traditional economics literature (Bogetoft and Wang, 2005; Kumar and Bansal, 2008). Bogetoft and Wang (2005) opened a new line of sight for assimilating mergers through production economics models. In particular, production models quantified the merger gain through operational efficiency perspective. Further, decomposition of the merger efficiency is carried out with respect to individual performance and SE using DEA. The authors demonstrated application of the integration approach by merging agricultural institutions in Denmark and its significance is presented for various strategic business considerations (Bogetoft and Wang, 2005). In addition, Kumar and Bansal (2008) revealed significant improvements in operational performance of integrated firms. The internal reasons for integration include attaining economies of scale and scope along with risk mitigation. On the contrary, external integration comprise of merging independent firms for gaining market share and accessing contemporary innovation capabilities (Bogetoft and Wang, 2005).

Cooper *et al.* (2006, 2007) demonstrated application of DEA for a merger simulation of the Japanese banks undergoing recession in 1990s. The main reason for recession related to decline in the real estate prices which had been enormously supported by these banks. In order to protect Japan's financial system, the Government suggested merger of low performing banks as one of the re-structuring strategies for competitive survival (Bogetoft and Wang, 2005; Cooper *et al.*, 2006, 2007). The authors conducted DEA merger analysis of regional and city banks with respect to efficiency and RTS characteristics. In particular, three inputs in the form of number of branches and employees along with assets are considered. Similarly, net operating profit in Yen is viewed as the output. The corresponding inputs and output of the '*To-Be*' merged banks are combined hypothetically using projection details to form a virtual merger for performance evaluation.

Walter and Cullmann (2008) further applied Bogetoft and Wang's (2005) approach for assimilating merger gains of local transportation system in Germany. Due to competitive bidding of contracts and profitability issues, the transportation companies looked at mergers with local partners. The findings reported 16 per cent operational gains from the mergers leveraging synergy in the transportation system. In general, cost savings from the business process is deemed as one of the important factors to attain synergy in a merger. In order to address outliers in the dataset, the authors applied DEA evaluation for merger efficiency along with bias correction factor using bootstrapping technique. Further, Walter and Cullmann (2008) and Bogetoft and Wang (2005) collectively reported that tremendous scope exists for further research in diverse applications.

Brekalo *et al.* (2013) and Lukkari (2011) mentioned that dynamic capabilities in measuring merger performance are neglected. The authors warranted development of an effective dynamic integration framework. Wu *et al.* (2013) formulated a multi-period dynamic DEA model to evaluate pre and post merger scenario. Davoodi and Rezai (2014) demonstrated utilisation of DEA models for evaluating the merger efficiency. Alternatively, Nolan *et al.* (2014) reported that mergers in the logistics industry can be analysed through economies of scale which can be attained through resource sharing and cost reduction of operations. The authors analysed mergers in airline industry and found positive gains from the integration process. Besides, mergers in the logistics industry enhance market coverage and operational stability between the network members in a SC. In parallel, Kirlulak and Erdem (2014) applied DEA for measuring the performance of merged firms during pre and post financial crisis using OE parameters. Therefore, achieving substantial operational improvement through mergers is deemed as the key requirement to create synergies across different categories of trading partners. Specifically, synergy leads to improvement in OE and value additions between the network members (Ray and Ray, 2014). Sinkovics *et al.* (2015) examined implementation of mergers at operational level from marketing perspective. The authors found through cross-category comparison that the synergy factor improves integration between different mergers. Also, interaction and speed of integration are negatively related, and the study did not include partnership measurements. In summary, adopting a slow and steady process signifies better integration capabilities calling it as "*merger syndrome*". Taking cue from this, the 4PL transaction centre is modelled in two steps as it involves merging *best of breed* trading partners in a common platform. In the next section, assumptions and parameters considered for the research study are exhibited.

5.2 Assumptions, Parameters and Models

5.2.1 Assumptions

The assumptions include,

- The coordinator of transaction centre has the capability to conduct cross-segment trading partner integration with requisite skill sets and analytical capabilities. Further, the coordinator understands the dynamics of buying organisation's industry to manage 4PL operations
- Apart from TE, efficiency calculation with cost consideration has been looked for the study. The variable inputs and corresponding unit costs has been viewed as positive. Besides, this type of efficiency has been termed as Allocative Efficiency
- For the development of 4PL transaction centre, 80^{th} percentile model solution data fit in the normal distribution has been considered as benchmark for acceptability. Nonetheless, the benchmark level can be subsequently raised based on precision and accuracy requirements
- Due to limited information about DEA efficiency distribution, non-parametric statistics has been applied for validation of optimal merger stability. Further, Wilcoxon signed-rank test assumes the distribution of differences between sensitivity datasets as symmetric and mutually independent

5.2.2 Parameters

The parameters considered for the study consist of,

- $\boldsymbol{C} = c_j = (c_1, \ldots\ldots, c_m)$ = Common Unit Input Cost Vector
- $C(y_{io})$ = Cost of Cross-Segment Merger i
- C_b = Bias Correction Factor
- $\mathbf{H_o}$ **=** Null Hypothesis

- **H_1 =** Alternate Hypothesis
- Lz_i = Lower Bound Dataset
- N_w = Pre-defined Window Time Frames
- P = Production Possibility Set
- P_c = Cost based Production Possibility Set
- SE = Scale Efficiency
- S_r = Ratio of Standard Deviation of Actual and Model Predicted Value
- S_X = Standard Deviation of Model Predicted Value
- S_Y = Standard Deviation of Actual Value
- S_i^-, S_r^+ = Slack and Surplus Variables for Input-Output Vectors
- Uz_i = Upper Bound Dataset
- U^D = Random Error
- U^M = Mean Bias
- U^R = Slope Bias
- $\mathbf{X}$ = x_j = Input Vectors
- $\mathbf{X_c}$ = x_{cj} = $(c_1x_1, \ldots\ldots\ldots, c_{mj}x_{mj})^T$ = Input Measured by Cost
- X_c^* = Optimised Input Measured by Cost
- $\mathbf{Y}$ = y_j = Output Vectors
- Y_i = Response Variable in the Form of Actual Merger Cost
- Z **=** Binary Decision Variable Satisfying 0 or 1 Condition
- b_j = Slope of Regression Line j
- **e** = Row Vector with all Elements Unity
- $f(X_i)$ = Proposed Model Merger Cost
- $\bar{f}(\chi_i)$ = Mean of Model Predicted Value
- k = Time Period
- k_o = Optimised Total Input Cost
- k_1 = Total Input Cost
- l_w = Length of Window

- m = Number of Inputs
- n = Number of DMUs
- r = Pearson's Correlation Coefficient
- s = Number of Outputs
- v = Total Optimised Input Cost
- v_{ij} = Variable Input Cost of i Category Trading Partner and j DMU
- v_i^* = Efficient Individual Input Cost of i Category Trading Partner
- $\mathbf{x^*}$ **=** Optimised Input
- x_o = Input under Study
- y_{ij} = Output of i Category Trading Partner and j DMU
- y_o = Output under Study
- $\bar{y}$ = Mean of Response Variable through Actual Merger Cost
- α = Significance Level, %
- α^* = Allocative Efficiency
- Γ_i = Virtual Sensitivity Dataset for i Input-Output
- θ = Input Oriented Efficiency
- θ^* = Optimal Input Oriented Efficiency
- θ^*_{CCR} = Technical Efficiency
- θ^*_{BCC} = Pure Technical Efficiency
- $\boldsymbol{\lambda} = \lambda_j$ = Column Vector of Inputs and Outputs for Input Oriented DEA Model
- ς^* = New Cost Efficiency
- $\phi*$ = New Technical Efficiency
- ρ_c = Concordance Correlation Coefficient
- Λ = Amalgamated Mean
- Λ_1 = Amalgamated Mean of Actual Value
- Λ_2 = Amalgamated Mean of Model Predicted Value
- δ = Stability Radius of the Cross-Segment Merger
- δ^* = Optimal Stability Radius of the Cross-Segment Merger

- ψ = Pre-Defined Efficiency Score
- Ω_i = DMU Classification i

5.2.3 Mathematical Formulation of the Transaction Centre for Cross-Segment Integration

By virtue of the attained performance results, implementation of cross-segment integration in the 4PL transaction centre has been addressed in this chapter using projection details. Specifically, cross-segment integration in the transaction centre involves quantifying the merger gains to support 4PL operations. The proposed formulation for cross-segment integration (step-2) in the 4PL transaction centre has been depicted in fig. 5.3.

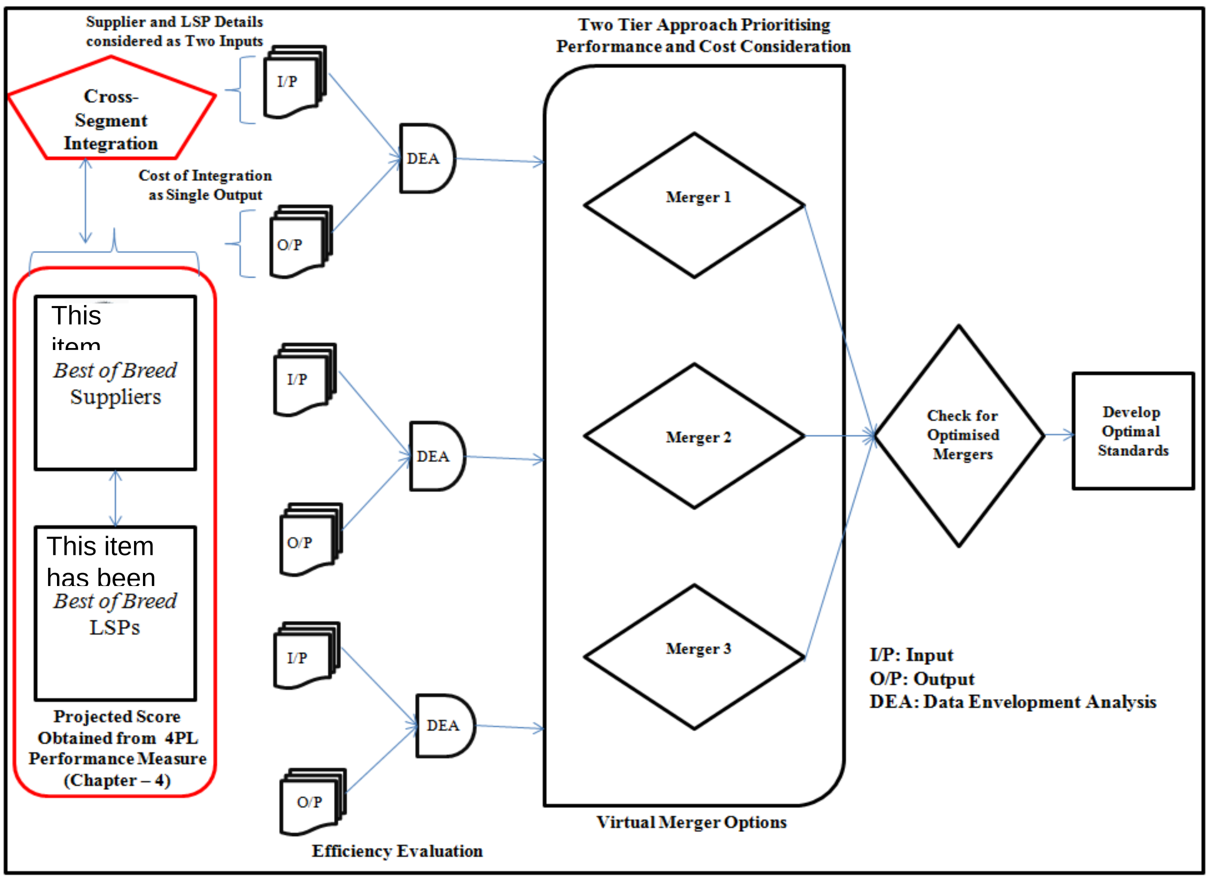

Figure 5. 3 Formulation for cross-segment integration in 4PL transaction centre

In order to identify inputs and outputs for estimating DEA merger efficiency, projected score from the proposed 4PL performance measurement framework has been considered to interlink evaluation and integration process. In particular, suppliers and LSP performance output (chapter – 4) has been viewed as distinct inputs for modelling 4PL transaction centre (chapter – 5) and the cost of integration with regard to these inputs has been looked as common output. The rationale for considering projection score from the recommended performance measure relates to the 4PL principle of dealing with *best of breed* trading partners (Fulconis *et al.*, 2007; Richey *et al.*, 2009). In principle, guiding the evaluation outputs as inputs for cross-segment integration in the 4PL transaction centre has been regarded as one of the original contribution. After integrating cross-segment trading partners into virtual mergers (Eg: suppliers and LSPs), DEA evaluation has been carried out for all the combinations. In addition, virtual mergers have been examined by means of a two-tier approach prioritising performance and cost orientation respectively. Finally, mergers have been selected based on the intended theme of model development and the optimal standards for cross-segment integration have been derived.

This thesis extends Bogetoft and Wang's (2005) production economics model to the 4PL transaction centre for carrying out integration from similar-segment mergers to cross-segment mergers. The transaction centre model of 4PL that can be used to optimally integrate trading partners has been created in a two tier approach. First tier of the proposed model evaluates virtual mergers (Eg: suppliers and LSPs) through OE parameters considering cost and technical aspects simultaneously. In case of tie-situation in OE score, cost factor of the merger has been viewed in the second tier approach to select optimal mergers. In principle, a two tier approach has been proposed prioritising performance orientation in first tier and cost orientation in second tier respectively. Figure 5.4 shows the proposed framework for selecting optimal cross-segment combination in the transaction centre from virtual mergers. Here, different categories of trading partners have been integrated into cross-segment mergers with all possible situations in the 4PL transaction centre. In the first tier, highest OE score among the virtual mergers has been considered as optimal integration combination. However, in case of tie-situations, least cost of the virtual merger has been looked in the second tier approach. By virtue of this, operating standards to perform cross-segment integration has been derived in the proposed 4PL transaction centre. In summary, the proposed research puts forward OE of the merger along with providing information about individual performance parameters of the trading partners.

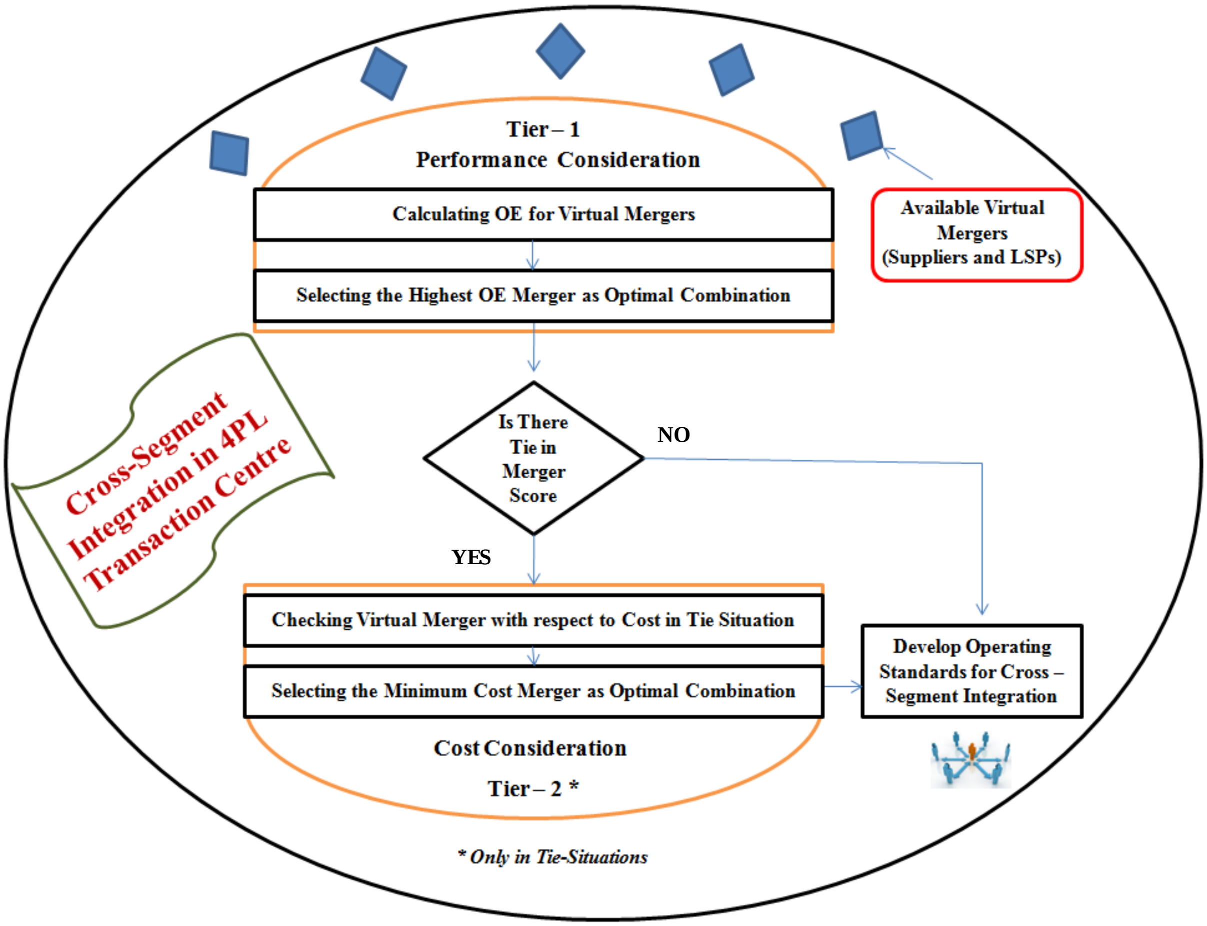

Figure 5. 4 Proposed framework for selecting optimal merger in 4PL transaction centre

As the proposed framework revolves around OE, a clear understanding of this concept is needed. In general, OE calculation factors in TE and cost efficiency together to achieve completeness in an evaluation process (Cooper *et al.*, 2007; Ray and Ray, 2014). The rationale for applying OE to the transaction centre has been based on the fact that cross-segment trading partners may have advantages either in terms of technology or cost. Moreover, the cost related efficiency is termed as AE. Therefore, technology and cost criteria play a critical role (Cooper *et al.*, 2007) in merging cross-segment trading partners which helps the coordinator to use resources optimally. Figure 5.5 depict the concepts of TE, AE and OE for common unit input costs c_j. As reported, solid lines in the below figure represent an iso-quant which points out all possible combinations of inputs $\mathbf{X} = (x_1, x_2)$ to produce equal amount of outputs $\mathbf{Y}$.

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Figure 5. 5 Concepts of TE, AE and OE

Source: Adapted from Cooper et al. (2007)

Further, point 'P' is considered as an inefficient DMU in the production possibility set to produce same amount of output with greater inputs. By definition, input oriented efficiency θ can be represented as shown in expression (5.1).

$$0 \leq \frac{d(O,Q)}{d(O,P)} \leq 1 \qquad \text{………………. (5.1)}$$

Here, *d(O,Q)* means distance from O to Q and *d(O,P)* represents distance from O to P. In order to bring cost consideration (AE), the cost line passing through point 'P' has been represented by expression (5.2) where k_1 signifies total input cost.

$$c_1x_1 + c_2x_2 = k_1 \qquad \text{………………. (5.2)}$$

However, this total cost can be optimised by moving this line downwards till it intersects point 'C'. The optimised input cost k_0 can be represented as shown in expression (5.3).

$$c_1x_1^* + c_2x_2^* = k_0 \qquad \text{………………. (5.3)}$$

In this case, $k_0 < k_1$. Nonetheless, point 'C' has been attained as the optimised input solution x^* of the following LPP:

$$\boldsymbol{C}x^* = \min.\ c_j x_o$$

subject to constraints

$$x_o \geq \mathbf{X\lambda}$$

$$y_o \leq \mathbf{Y\lambda} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5.4)$$

$$\mathbf{e}\ \boldsymbol{\lambda} = 1$$

$$\boldsymbol{\lambda} \geq 0$$

where $\boldsymbol{C} = c_j = (c_1, \ldots\ldots\ldots\ldots.., c_m)$ represents common input cost vector for m inputs, **e** be row vector with all elements unity and **λ** denotes input-output column vectors. The suffix 'o' denotes input-output parameter under study. Likewise, AE can be represented as shown in expression (5.5). This provides the measure that technically efficient point Q falls short of becoming cost efficient.

$$0 \leq \frac{d(O,R)}{d(O,Q)} \leq 1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5.5)$$

where *d(O,R)* means distance from O to R and *d(O,Q)* represents distance from O to Q. Lastly, OE can be represented as shown in expression (5.6).

$$0 \leq \frac{d(O,R)}{d(O,P)} = \frac{cx^*}{cx_o} \leq 1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5.6)$$

where *d(O,R)* means distance from O to R and *d(O,P)* represents distance from O to P. In order to relate all these three efficiencies, it can be mathematically expressed as follows:

$$\frac{d(O,R)}{d(O,P)} = \frac{d(O,R)}{d(O,Q)} * \frac{d(O,Q)}{d(O,P)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ (5.7)$$

Alternatively, this can be written as shown in expression (5.8a) which can be further signified in expression (5.8b).

$$OE = AE * TE \quad \text{……............. (5.8a)}$$

$$OE = AE * PTE * SE \quad \text{……………… (5.8b)}$$

where PTE = optimal input oriented BCC score θ^*_{BCC}, TE = optimal input oriented CCR score θ^*_{CCR} and SE = θ^*_{CCR} / θ^*_{BCC}. Furthermore, AE has been mathematically represented as α^*. This can be defined as the ratio of new cost efficiency ς^* to new technical efficiency $\phi*$ which has been represented as follows:

$$\alpha^* = \frac{\varsigma^*}{\phi^*} \quad \text{……………… (5.9)}$$

Further, analysis results from chapter-4 has been summarised and collated along with the projection details of 112 suppliers (all categories included) and 10 LSPs. For the model development of transaction centre, suppliers and LSPs have been categorised into different clusters based on their geographical spread. In order to link evaluation and integration, projection details of '*Quantity Accepted*' in supplier evaluation and '*Weight Shipped*' relating to LSP evaluation has been proposed as inputs and the cost of integration has been viewed as common output as depicted in fig. 5.6. Here, the projected input reflects '*TO BE*' status or expected operational benchmark level. As suppliers and LSPs belong to different category, an attempt to integrate cross-segment trading partners in the form of a merger has been proposed in this thesis. On the other hand, '*Combined Revenue Spend in USD*' obtained through integration costs of both the projected inputs have been considered as common output (Chu *et al.*, 2004). All categories of suppliers in the pre-defined clusters have been combined with corresponding LSPs to arrive at virtual mergers. From the virtual mergers secured, optimal standards for merging cross-segment DMUs through OE and cost calculations have been derived. Therefore, datasets have been prepared considering cost factor in USD along with θ and SE.

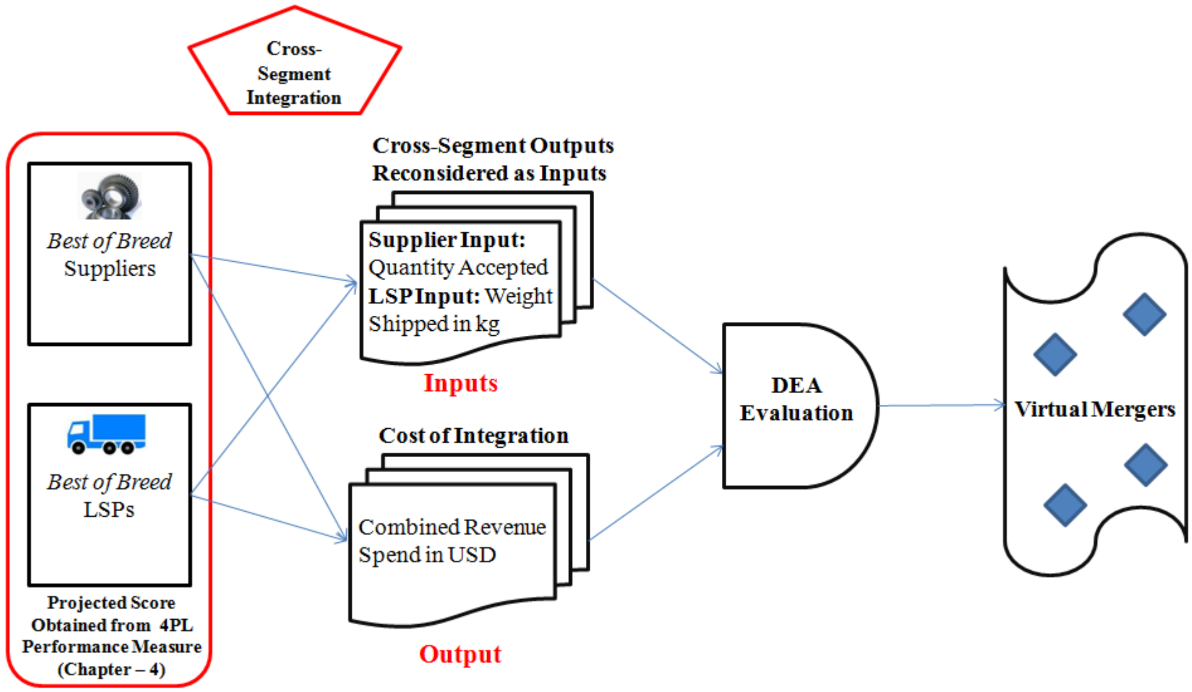

Figure 5. 6 Proposed framework to inter-link evaluation and integration

As demonstrated by Bogetoft and Wang (2005), the integration has been carried out through direct pooling of j^th inputs $\sum_{j \in n} x_j$ and outputs $\sum_{j \in n} y_j$ for n DMUs using input oriented radial measure. Besides, the additive assumption for inputs (x_1, x_2) and outputs (y_1, y_2) belonging to the same Production Possibility Set P can be demonstrated as follows:

If $(x_1, y_1) \in P$ and $(x_2, y_2) \in P$ then the integrated inputs and outputs belongs to P

$$i.e; \quad (x_1 + x_2, y_1 + y_2) \in P \qquad \text{.........................} (5.10)$$

Whenever x_1 input produces y_1 output and x_2 input contributes y_2 output respectively; then the integrated inputs $(x_1 + x_2)$ must produce at least integrated output $(y_1 + y_2)$. Moreover, the additive function for integration has advantages over economic literatures with reference to scaling and convexity assumptions (Walter and Cullmann, 2008; Bogetoft and Wang, 2005). In particular, these assumption leads to lesser average efficiency scores compared to additive function (Walter and Cullmann, 2008). Thus, additive function has been considered for integrating cross-segment trading partners (suppliers and LSPs) in this thesis. Due to cross-segment integration, the inputs (x_1, x_2) have been viewed separate and the common output has been integrated using additive function as depicted in fig. 5.6. Based on Kirlulak and Erdem's (2014) and Ray and Ray's (2014) work, OE parameter has been considered to quantify the merger gain for all the available combination of cross-segment integration options. In parallel, decomposition of the OE parameters help the mergers to assimilate their performance with respect to other virtual mergers. Specifically, improvement directions can be examined for the attained virtual mergers by identifying alternative strategies to improve the merger gain. The condition mentioned in expression (3.4) has been satisfied before inter-linking input-output parameters of the mergers. In addition, mathematical formulation of the intended transaction centre has been carried out under v-RTS due to the diverse scope and scale of trading partners. Similarly, cross-segment virtual mergers of suppliers and LSPs have been interpreted as shown in figure 5.7 for 'C04' supplier and 'L01'LSP as an example.

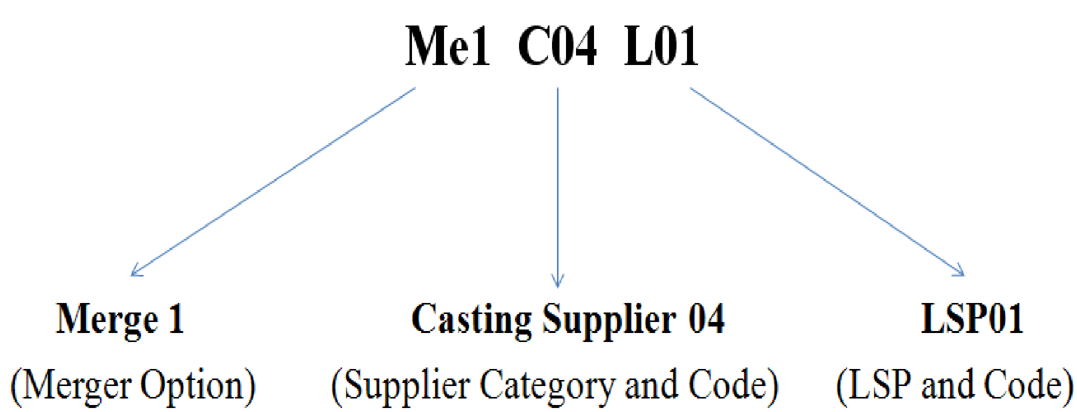

Figure 5. 7 Trading partner merging interpretation

The first alphanumeric division signifies the merger option, second alphanumeric allotment denotes supplier category with code and third alphanumeric division refers to LSP with code. Development phases of the 4PL transaction centre has been exhibited in figure 5.8 to accomplish OE and merger cost as follows:

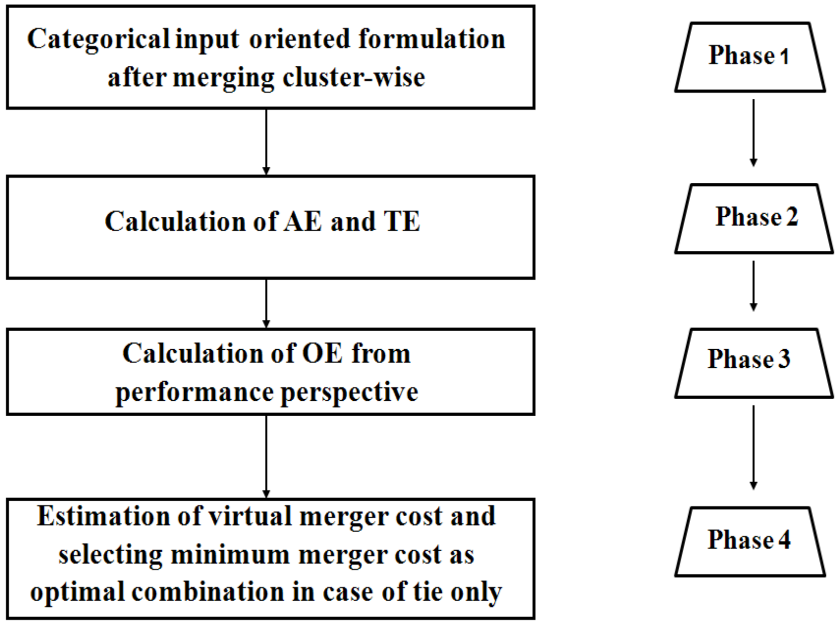

Figure 5. 8 Phases of 4PL transaction centre model development

Phase 1: Input Oriented Categorical Formulation

In order to calculate θ and SE, the input oriented categorical model has been applied. Besides, categorical formulation has been considered for modelling based on the results attained from the proposed *Make-Shift* methodology. The LPP for the selected input-output dataset (x_o, y_o) has been mathematically formulated as follows:

$$\begin{gathered} \text{Min. } \theta \\ \text{subject to constraints} \\ \theta x_o - \mathbf{X}\boldsymbol{\lambda} \geq 0 \\ \mathbf{Y}\boldsymbol{\lambda} \geq y_o \\ \boldsymbol{\lambda} \geq 0 \end{gathered} \qquad \text{........................ (5.11)}$$

To capture the categorical effect, LPP has been formulated by not considering upper category DMUs as basic variables with reference to lower category DMUs. Similarly, LPPs for all the cross-segment mergers have been formulated and solved using simplex method. By virtue of RTS characterisations for the above DEA model, θ^*_{CCR} and θ^*_{BCC} has been found along with SE. In the next phase, efficiency calculation with respect to cost has been addressed.

Phase 2: Allocative Efficiency α^* Calculation

With reference to expression (5.9), it is essential to compute new cost efficiency ς^* and new technical efficiency ϕ^*. However, the meaning of AE considering equal input costs has been elucidated in fig. 5.6. But in the real world scenario, application of this concept turns to be a limitation. Hence, calculation of ς^* and ϕ^* becomes necessary with variable input costs. To capture this effect, the traditional P as shown in expression (5.12a) has been modified into cost based production possibility set P_c as indicated in expression (5.12b) by multiplying cost c_j with input x_j known as x_{cj}. This has been carried out because P confines to only technical factors.

$$P = \{(X, Y) | x \geq X\lambda, y \leq Y\lambda, e\lambda = 1, \lambda > 0 | \} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(5.12a)}$$

$$P_c = \{ \left(X_c, Y \right) \Big| x_c \geq X_c\,\lambda, y \leq Y\lambda, e\lambda = 1, \lambda > 0 \Big| \} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(5.12b)}$$

Here, $X_c = (x_{c1}, \ldots\ldots. x_{cm})$ with $x_{cj} = (c_1 x_1, \ldots\ldots\ldots, c_{mj} x_{mj})^T$ assuming matrices $\boldsymbol{X}$ and $\boldsymbol{C}$ as positive. Hence, it becomes imperative to compute new cost and new technical efficiency to calculate α^*.

<u>New Cost Efficiency</u> (ς^*):

The mathematical formulation for ς^* has been based on the P_c which can be represented as shown in expression (5.13).

$$\varsigma^* = \frac{\sum e \overset{*}{x}_{co}}{\sum e\, x_{co}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(5.13a)}$$

Where $\overset{*}{x}_{co}$ in the numerator of expression (5.13a) signifies optimal input solution obtained from the LPP. The denominator represents actual input obtained from the dataset. Further, the expression (5.13a) has been re-organised for the study with two input costs as shown in expression (5.13b) as an instance.

$$\varsigma^* = \frac{\sum e \overset{*}{x}_{co}}{\sum e\, x_{co}} = \frac{\sum c_1 \overset{*}{x}_o + c_2 \overset{*}{x}_o}{\sum c_1\, x_o + c_2\, x_o} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(5.13b)}$$

In order to get the value of numerator, the LPP formulation has been applied as shown in expression (5.14).

$$\begin{gathered} \text{Min. } e\,x_{co} \\ \text{subject to constraints} \\ x_{co} \geq X_c\,\lambda \\ y_o \leq Y\lambda \\ \mathbf{e\lambda} = 1 \\ \boldsymbol{\lambda} \geq 0 \end{gathered} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ (5.14)$$

<u>New Technical Efficiency</u> (ϕ^*):

Subsequently, ϕ^* has been calculated. The LPP for calculating optimal technical efficiency has been represented in expression (5.15).

$$\begin{gathered} \Phi^* = \text{min. } \phi \\ \text{subject to constraints} \\ \Phi x_{co} \geq X_c\,\boldsymbol{\lambda} \\ y_0 \leq \mathbf{Y\lambda} \\ \mathbf{e\lambda} = 1 \\ \lambda \geq 0 \end{gathered} \qquad \ldots\ldots\ldots\ldots\ldots\ (5.15)$$

Here, X_c has been estimated by multiplying actual input with the corresponding cost. From the secured ς^* and ϕ^* scores, α^* has been calculated using expression (5.9). In principle, α^* identifies inefficiencies due to the cost factor in virtual mergers with the help of P_c. Consequently, selection of optimal mergers with regard to OE has been reported in the next phase.

Phase 3: OE Calculation

In this phase, reconciliation of the proposed model conditions has been viewed with regard to OE. Furthermore, mergers with the highest OE score have been given preference.

Specifically, priority has been given to performance as compared to cost for the model development. After calculating PTE, SE and AE in the preceding phases, OE has been computed using expression (5.8). In principle, OE helps the 4PL coordinator to evaluate and critique the cross-segment integration from technical as well as cost perspective simultaneously. Likewise, coordinator has the option to select optimal mix of trading partners from the transaction centre pool for a given scenario to manage 4PL operations. Hence, the developed model selects optimal cross-segment mergers based on the highest OE scores (tier-1). The notion behind model development in the first tier approach dwells upon performance oriented perspective. In the next phase, tier-2 approach for selecting optimal mergers has been proposed to address tie-situation in OE scores.

Phase 4: Merger Selection with respect to Cost in Tie-situation

In the tier-2 approach, tie-situation obtained from the OE calculation has been addressed. Priority in selecting optimal mergers has been shifted from performance to cost oriented approach. For this reason, merger cost has been looked as a quantifiable decision variable to critically analyse cross-segment integration. The DEA cost-merger model has been applied considering variable input costs v_{ij} and outputs y_{ij} for trading partner category i and DMU j. For the study, two DMU categories merged with input costs and individual outputs has been represented as (v_1, y_{1o}) and (v_2, y_{2o}) respectively. Initially, cost inefficiencies from individual trading partners have been removed using input oriented categorical model represented in expression (5.11). From the results secured, corresponding outputs has been represented for the two categories of trading partners as (v_1^*, y_{1o}) and (v_2^*, y_{2o}). By integrating the cross-segment trading partners into a merger through efficient individual input cost v_i^*, total optimised input cost v has been attained using expression (5.16) along with distinct outputs.

$$v = \sum v_i^* \qquad \text{……………..} \ (5.16)$$

By virtue of this, cost of the merger $C(y_{io})$ has been obtained for n DMUs with s outputs through the following LPP:

$$C(y_{io}) = \text{min. } v\theta$$

subject to constraints

$$v\theta = c_1\lambda_1 + c_2\lambda_2 + \ldots\ldots\ldots\ldots\ldots. + c_n\lambda_n$$

$$y_{1o} \leq y_{11}\lambda_1 + y_{12}\lambda_2 + \ldots\ldots\ldots\ldots\ldots. + y_{1n}\lambda_n$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$y_{so} \leq y_{s1}\lambda_1 + y_{s2}\lambda_2 + \ldots\ldots\ldots\ldots\ldots. + y_{sn}\lambda_n$$

$$1 = \lambda_1 + \lambda_2 + \ldots\ldots\ldots\ldots\ldots. + \lambda_n \qquad \ldots\ldots\ldots\ldots (5.17)$$

$$\boldsymbol{\lambda} \geq 0$$

Further, the cost of virtual merger has been compared with all possible options available in the transaction centre. Finally, least merger cost has been selected as the optimal merger. In this way, tie-situation of OE scores has been addressed in the proposed cross-segment integration framework for 4PL transaction centre. Additionally, operating standards can be deduced which assists the coordinator to manage 4PL operations for a given situation. The key message from this chapter highlights that a first attempt to model 4PL transaction centre for integrating cross-segment trading partners from operations perspective has been executed. Thus, development of an exclusive 4PL transaction centre for managing integration process of different trading partner categories has been presented. In the subsequent section, the proposed model evaluation through data variation along with validation has been signified.

5.2.4 Evaluation and Validation of the Proposed Transaction Centre Model

The intended model portrays mathematical representation of 4PL transaction centre which can provide operating standards for merging trading partners. In common, the mathematical model consists of conceptual model, equations and modelling data to portray actual scenario (Thacker *et al.*, 2004). Nonetheless, sustainability of the proposed model has been evaluated to test the model adequacy (Tedeschi, 2004). Thus, assessment of the model has been carried out through data variation and combination of statistical analysis (Tedeschi, 2004; Thacker *et al.*, 2004). In addition, an investigation to review the purpose of conceptualised model (Thacker *et al.*, 2004) has been executed. Moreover, the evaluation of the suggested model signifies level of precision and accuracy of the operating standards for merging trading partners in this thesis. In general, accuracy measures the model's ability to predict closer to the actual value and precision determines the model's capability to predict similar values consistently (Tedeschi, 2004). Further, verification and validation methodology has been applied to the recommended transaction centre. This methodology has been used as an evidence to derive operating standards for integrating cross-segment trading partners with quantified confidence (Thacker *et al.*, 2004) and deemed essential for the model development. Moreover, research on synthesising mathematical models has critically warranted for the need of verification and validation methodology. Verification highlights on identifying and eliminating errors; validation emphasises on quantification of accuracy through data variations (Thacker *et al.*, 2004; Tedeschi, 2004). In this thesis, performance metrics for optimally managing the transaction centre of 4PL has been put forward.

The proposed model has been evaluated by comparing merger cost of trading partners between legacy (actual) and proposed situation. In this research, legacy data has been obtained through company's record using IC-soft ERP software and the stores department data for a particular time period. Detailed procedure of collecting actual data has been already discussed in chapter-3 (see Section 3.4). Specifically, actual data considered for DEA performance evaluation and calculation of virtual merger efficiency has been viewed as legacy situation. In summary, actual merger cost for the specific period has been compared with the optimised merger cost obtained through the proposed model. In addition, mean and variance statistics between the legacy and the suggested model has been critically analysed along with individual plot (Aczel and Sounderpandian, 2008). The proposed operating standards for the 4PL transaction centre has been considered significantly better than the legacy situation. Adequacy of the proposed model considering precision and accuracy has been conducted utilising concordance correlation coefficient ρ_c (Tedeschi, 2004) denoted in expression (5.18). ρ_c evaluates the merger cost considering precision and accuracy simultaneously by verifying amalgamation along with unity line through the origin.

$$\rho_c = r * c_b \qquad \text{………………….} (5.18)$$

In the above expression, r signifies Pearson's correlation coefficient that measures precision and C_b means bias correction factor which indicates deviation of regression line (accuracy) from the slope of unity (45^0). Moreover, C_b has been estimated using expression (5.19).

$$c_b = \frac{2}{\left[S_r + \frac{1}{S_r} + \Lambda^2\right]} \quad \text{……………………. (5.19)}$$

where, $S_r = \frac{S_Y}{S_X}$ and $\Lambda = \frac{\Lambda_1 - \Lambda_2}{\sqrt{S_Y S_X}}$

Here, S_Y represent standard deviation of actual value, S_X be standard deviation of model predicted value, Λ denote amalgamated mean, Λ_1 refer to amalgamated mean of actual value and Λ_2 act as amalgamated mean of model predicted value. It has been reported that the proposed model has been regarded as credible compared to legacy. In the next step, ρ_c result has been validated using MEF. As a result, proportion of variation explained by the fitted regression line $Y_i = f(X_i)$ has been implied (Tedeschi, 2004) in expression (5.20) where Y_i denote response variable, $\bar{y}$ represent mean of response variable through actual merger cost and $f(X_i)$ be proposed model merger cost.

$$MEF = 1 - \frac{\sum_{i=1}^{n} \left(Y_i - f(X_i)\right)^2}{\sum_{i=1}^{n} \left(Y_i - \bar{Y}\right)^2} \quad \text{………………….. (5.20)}$$

Moving forward, the proposed 4PL transaction centre has been evaluated through data variation in two segments by dividing the dataset into training and verification dataset. In this thesis, the initial data considered for DEA analysis has been referred as training dataset and the data viewed for model evaluation has been viewed as verification dataset. In segment-1, DEA scores for training and verification dataset has been computed individually using the proposed multi-stage performance evaluation framework (chapter – 4) under both RTS characterisation. Nonetheless, the comparison examines performance potential of all the outputs in terms of dynamic efficiency. In addition, a pattern matching technique (Chen and Su, 2009) has been applied to compare and contrast the legacy and the proposed model results. Moreover, pattern matching in research emphasizes robustness of the proposed theories (Chen and Rossi, 1987). Also, consistency of the trading partners' performance has been examined through interval plot and validated applying bi-lateral comparison (Cooper *et al.*, 2006, 2007) along with Wilcoxon-Mann Whitney rank sum test (Aczel and Sounderpandian, 2008). In general, bi-lateral comparison technique envisages that each trading partner in **A** has been evaluated with respect to DMUs of **B** and vice versa (Cooper *et al.*, 2006, 2007). Hence, the bi-lateral comparison results in sharper discrimination. Figure 5.9 depicts the conceptual framework of bi-lateral comparison for trading partners in **A** with respect to **B** for two inputs (x_1, x_2) and single output (y_1). In case-1, trading partner 'a Є **A**' has been enveloped by DMUs in **B** and the radial efficiency θ has been calculated using expression (5.21). In case-2, trading partner 'a' has been expanded radially to Q and the θ has been shown in expression (5.22).

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Figure 5. 9 Bi-lateral comparison conceptual framework

Source: Cooper et al. (2007)

$$\theta = \frac{OQ}{OP} \leq 1 \qquad \text{……………………. (5.21)}$$

$$\theta = \frac{OQ}{OP} \geq 1 \qquad \text{..…………………….. (5.22)}$$

The mathematical formulation for bi-lateral comparison of DMU 'a ∈ **A**' with respect to **B** has been represented in expression (5.23).

$$\begin{aligned} &\text{Min. } \theta \\ &\text{subject to constraints} \\ &\sum_{j\in B} x_j \lambda_j \leq \theta x_a \\ &\sum_{j\in B} y_j \lambda_j \geq y_a \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.23) \\ &\lambda_j \geq 0 \left(\forall_j \in B\right) \end{aligned}$$

In order to validate the significant frontier shift between data variation models, Wilcoxon-Mann-Whitney non-parametric statistics has been applied due to the unknown distribution of DEA efficiency scores. The working principle of this non-parametric statistics has been reported in Appendix B.3. In continuation, an attempt to decompose the dynamic efficiency has been executed considering TE, PTE and SE. Decomposition of these efficiencies has been analysed through matrix plot to assess the relationships. Further, the matrix plot comparison identifies areas of improvement to attain consistency with individual parameters. In summary, the efficiency results of trading partners from the proposed performance evaluation framework have been consistent with data variation and statistically significant at 95% Confidence Interval (CI). By virtue of this, the proposed 4PL performance measurement framework for creating a *best of breed* setup has been assessed through data variation and statistically validated.

In segment-2, evaluation of the proposed 4PL transaction centre model for cross-segment integration has been carried out with regard to consistency and adequacy (Tedeschi, 2004). In particular, model consistency has been confirmed using OE parameters and model adequacy has been examined using decomposition of MSEP. Accordingly, OE parameters have been represented in expression (5.8). On the other hand, MSEP assess precision of the fitted linear regression model using the difference between actual values Y_i and model predicted values $f(X_i)$ for n DMUs as shown in expression (5.24).

$$MSEP = \frac{\sum_{i=1}^{n}\left(Y_i - f\left(X_i\right)\right)^2}{n} \quad \text{……..………….. (5.24)}$$

Therefore, MSEP has been calculated considering the legacy (actual merger cost) and the proposed model's optimal merger cost to analyse model adequacy. In addition, predictive accuracy decomposition has been performed with respect to error due to mean bias U^M, slope bias U^R and random error U^D, known as inequality proportion. The mathematical representation of these inequality proportions (Tedeschi, 2004) have been indicated as follows:

$$U^M = \left(\bar{f}(X_i) - \bar{Y}\right)^2 / MSEP \quad \text{………………….. (5.25)}$$

$$U^R = S_X{}^2 * (1 - b_j)^2 / MSEP \quad \text{...……………….... (5.26)}$$

$$U^D = \left(1 - r^2\right) * S_Y{}^2 / MSEP \quad \text{..………………… (5.27)}$$

Here, $\bar{f}\left(\chi_i\right)$ denote mean of the proposed model predicted values and b_j represent slope of regression line j. Thus, operating standards derived from the transaction centre for cross-segment integration has been evaluated through data variation. It has been observed that consistency prevails through data variation in the proposed transaction centre. In addition, the error decomposition of inequality proportion has been recommended as a criterion for improvement of precision and accuracy in the proposed 4PL transaction centre. Further, system efficiency DEA model has been suggested (Cooper *et al.*, 2006, 2007) to validate the derived operating standards with respect to merger efficiencies. The conceptual framework of system efficiency model for two stores comparison (**A** and **B**) with one input and two outputs has been signified in fig. 5.10. Besides, the system efficiency model compares merger efficiency in each system separately (model and actual). For instance, the efficient frontier would have been denoted as A1, A2, B7 and B10 if the distinction between systems have been neglected. Since, convexity condition does not apply to different systems (Cooper *et al.*, 2006, 2007); the efficiency frontier has been represented as A1, A2, A6, P, B7 and B10.

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Figure 5. 10 Comparison between stores using two Systems

Source: Cooper et al. (2007)

However, there might be a situation wherein the efficiency frontier of system-A may be below system-B as shown in the above figure. Thus, individual system efficiency might have the efficiency score greater than one depending on the situation of data points. The mathematical formulation of system efficiency model has been reported in expression (5.28) for two systems-A and B. In the below formulation, optimal input efficiency θ^* = Efficiency of DMU (x_o, y_o) = Min. { θ_A, θ_B }.

$$
\begin{gathered}
\text{Min. } \theta \\
\text{subject to constraints} \\
\theta x_o \geq \mathbf{X_A \lambda_A} + \mathbf{X_B \lambda_B} \\
y_o \leq \mathbf{Y_A \lambda_A} + \mathbf{Y_B \lambda_B} \\
L z_A \leq \mathbf{e \lambda_A} \leq U z_A \\
L z_B \leq \mathbf{e \lambda_B} \leq U z_B \\
Z_A + Z_B = 1 \qquad \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (5.28) \\
\lambda \geq 0 \\
Z_A, Z_B = \{0, 1\}
\end{gathered}
$$

Let, Z represent binary decision variable. Lz_i be lower bound dataset and Uz_i act as upper bound dataset. By virtue of system efficiency model, the minimum OE score among optimal merger options has been selected. In the next section, stability and sensitivity analysis of the proposed optimal mergers has been verified.

5.2.5 Stability and Sensitivity Analysis for the Selected Merger Combinations

Stability of the attained optimal mergers has been conducted employing window analysis in addition to system efficiency comparison. With wide acceptance of DEA analysis, research studies on window analysis has been limited (Sueyoshi *et al.*, 2013) with reference to 4PL transaction centre. Ideally, the window analysis in DEA approach can be utilised for smaller dataset of inputs-outputs due to degrees of freedom issues (Cooper *et al.*, 2007). In this thesis, two inputs (quantity accepted and weight shipped) and one output (optimal merger cost) has been considered for window analysis. Basically, each merger has been further divided into k-period within predefined window timeframes N_W. Further, the efficiency calculation in individual window timeframes has been computed by bringing the merger to the objective function of DEA model. Similarly, this procedure has been applied for all the cross-segment mergers with respect to individual window timeframe. After efficiency scores of the first row have been tabulated, initial data has been dropped and the successive data has been added to the new window. Nonetheless, N_W has to satisfy the length of window l_W condition. In summary, this procedure repeats until no further k-periods have been added to the data matrix. Moreover, results from the window analysis have been interpreted with respect to column and row views. Here, column observation examines the stability of results across different datasets with removal and replacement procedures. Row view determines the variation trends with regard to time period (Cooper *et al.*, 2007). Finally, the intended model and the window analysis results revealed similar optimal merger results. Moreover, stability in each optimal merger helps the coordinator of transaction centre to identify sensitive region to carry out cross-segment integration. Hence, sensitivity analysis has been executed to determine sufficient conditions for preserving efficiency status of the selected merger.

Sensitivity analysis has been considered as an important topic in DEA research (Abri *et al.*, 2009; Abri, 2012). In this thesis, Abri *et al.*'s (2009) sensitivity analysis framework has been utilised for the suggested transaction centre. Nonetheless, this framework adds flexibility by defining the new efficiency category along with stability radius estimation for individual mergers. The sensitivity analysis approach has been carried out in two steps. Step-1 focuses on classification of the mergers into efficient and inefficient category based on OE parameters.

Step-2 computes the stability radius δ for individual mergers. Besides, the model works with the notion that some processes of inefficient mergers have been considered similar to efficient mergers. For that reason, a new efficiency category known as quasi-efficient mergers has been formalised. However, these mergers have score greater than predefined efficiency score ψ determined by condition of the situation. Further, efficient and quasi-efficient mergers have been grouped into the same category. For instance, fig. 5.11 portrays 14 DMUs (A to N) with one input and output each along with their categorisation into efficient, quasi-efficient and inefficient DMUs.

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Figure 5. 11 Categorisation of DMUs

Source: Adapted from Abri et al. (2009)

The mathematical formulation for estimating δ has been indicated in expression (5.29a) for efficient and quasi-efficient DMUs:

Min. δ

subject to constraints

$$\sum_{j=1,\, j\neq o}^{n} x_{ij}\lambda_j + s_i^- - \delta = x_{io}$$

$$\sum_{j=1,\, j\neq o}^{n} y_{rj}\lambda_j - s_r^+ + \delta = y_{ro} \qquad \text{.............. (5.29a)}$$

$$\sum_{j=1,\, j\neq o}^{n} \lambda_j = 1$$

Similarly, mathematical formulation for estimating δ has been indicated in expression (5.29b) for inefficient DMUs:

$$\text{Max. } \delta$$

subject to constraints

$$\begin{aligned} &\sum_{j=1}^{n} x_{ij}\lambda_j + S_i^- + \delta = x_{io} \\ &\sum_{j=1}^{n} y_{rj}\lambda_j - S_r^+ - \delta = y_{ro} \qquad \text{.................. (5.29b)} \\ &\sum_{j=1}^{n} \lambda_j = 1 \end{aligned}$$

Let i = 1, ….., m and r = 1, ……., s for m inputs and s outputs, S_i^-, S_r^+ denote corresponding slack and surplus variables of inputs-outputs. Figure 5.12 exhibits sensitivity analysis framework applied to the recommended transaction centre of 4PL.

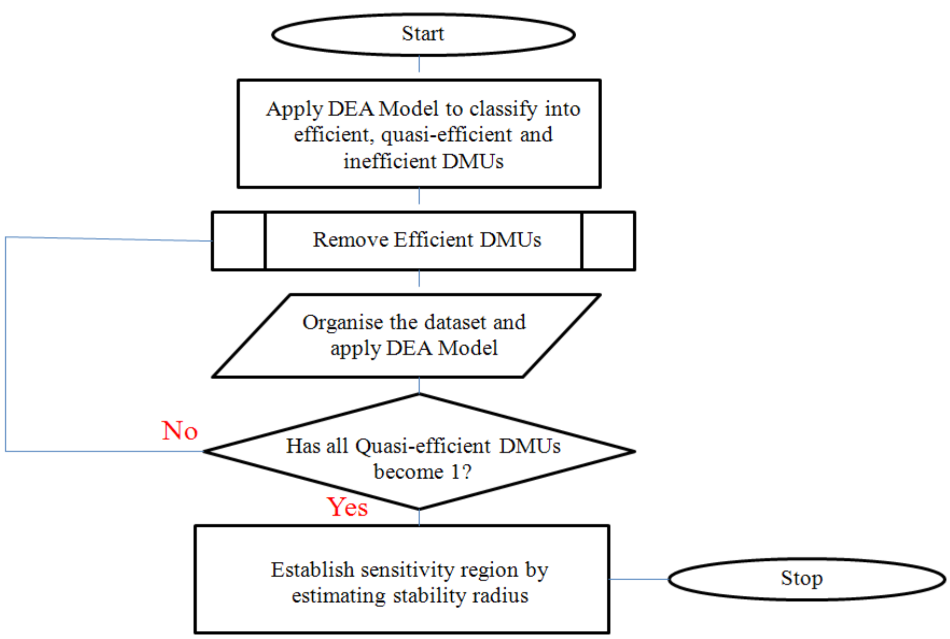


Figure 5. 12 Sensitivity analysis framework

The above mentioned framework has been explained by conducting DMU classification Ω_i with following conditions:

Let, Ω_1 consists all efficient DMUs ($\theta^* = 1$)

Ω_2 consists quasi-efficient DMUs ($\theta^* \sim 1$)

Ω_3 consists completely inefficient DMUs ($\theta^* \leq \psi$)

Ω_4 consists of quasi-efficient DMUs whose efficiency score became one recently

Subsequently, Ω and Ω' have been estimated using following expressions:

$$\Omega = \frac{(\Omega_1 \cup \Omega_2)}{\Omega_4} = (DMU_1, \ldots\ldots., DMU_L) \qquad \ldots\ldots\ldots\ldots\ldots (5.30)$$

$$\Omega' = (\Omega_3 \cup \Omega_4) = (DMU_{j1}, \ldots\ldots., DMU_{je}) \qquad \ldots\ldots\ldots\ldots\ldots (5.31)$$

By adding each member of Ω to Ω', virtual sensitivity dataset Γ_i has been individually synthesised as follows:

$$\Gamma_1 = \{DMU_{j1}, \ldots\ldots, DMU_{je}, DMU_1\}$$

$$\Gamma_2 = \{DMU_{j1}, \ldots\ldots, DMU_{je}, DMU_2\}$$

$$\vdots$$

$$\Gamma_L = \{DMU_{j1}, \ldots\ldots, DMU_{je}, DMU_L\} \qquad \ldots\ldots\ldots\ldots\ldots (5.32)$$

After collating Γ_i, DEA technique has been applied to arrive at optimal stability radii δ^*. In this way, sensitivity analysis has been carried out considering the stability radius. In summary, the stability region has been obtained and verified for optimal mergers of the transaction centre with regard to OE parameters. Moreover, the sensitivity analysis helps the coordinator to align and optimise the merger options by knowing the stability limits of individual trading partner (Abri, 2012). Lastly, cross-validation of the sensitivity region has been executed employing non-parametric Wilcoxon signed-rank test (Aczel and Sounderpandian, 2008) with respect to OE scores (see Appendix C.1). In statistical parlance, validation of already validated models has been considered as cross-validation methodology (Arlot, 2010). This non-parametric test does not require assumptions about the population parameter distribution and conducts pair-wise comparison of the two population datasets using median difference. Here, Wilcoxon test accounts for the magnitude of differences between paired values. Therefore, sensitivity analysis has been warranted to estimate the stability region for integrating trading partners for the proposed 4PL transaction centre. To show applicability and strength of the developed transaction centre model, the selected tiller and tractor manufacturing company data has been utilised in the form of case study.

5.3 Industry Case Study

Following the concepts, supplier and LSP datasets has been considered to ascertain the viability of transaction centre for cross-segment integration. The model has been created in a format that can provide operating standards for integrating cross-segment trading partners to manage 4PL operations.

5.3.1 Segregation of Cross-Segment Trading Partners

Due to differential pricing of local LSPs, the number of suppliers for model development percolates down to 49 suppliers. As 10 LSPs have been divided into three clusters, 49 suppliers have been further sub-divided cluster-wise based on their region. Therefore, cluster-1 has 21 suppliers and 2 LSPs; cluster-2 has 16 suppliers and 3 LSPs; and cluster-3 has 12 suppliers and 5 LSPs respectively. Details of individual suppliers in numbers have been shown cluster-wise as follows:

Table 5. 1 Cluster-wise segregation of suppliers for modelling 4PL transaction centre

Sl. No.	Category	Gears Supplier	Castings Supplier	Sheet Metal Supplier	Turned and Machined Supplier	Total
1	Cluster 1	1	11	3	6	21
2	Cluster 2	1	15	-	-	16
3	Cluster 3	4	2	1	5	12
Grand Total						**49**

In addition, cluster-wise details of individual suppliers and related LSPs has been reported in table 5.2.

Table 5. 2 Cluster-wise details of suppliers and LSPs

Sl. No.	Category	Gears Supplier	Castings Supplier	Sheet Metal Suppliers	Turned and Machined Suppliers	LSPs
1.	Cluster 1	G20	C01, C04, C05, C07, C09, C13, C14, C15, C19, C20, C26	S21, S29, S30	M05, M09, M19, M24, M28, M30	L01 L02
2.	Cluster 2	G19	C02, C03, C06, C08, C10, C11, C12, C17, C18, C22, C23, C24, C25, C27, C28	-	-	L03 L04 L05
3.	Cluster 3	G03 G04 G07 G18	C16, C21	S04	M03, M04, M22, M32, M34	L06 L07 L08 L09 L10

Thus, the development of transaction centre has been carried out considering 49 suppliers and 10 LSPs with all possible combinations based on their respective cluster. The input and output parameters has been obtained from the proposed framework to inter-link evaluation and integration for the development of transaction centre as shown below:

Table 5. 3 Input and output parameters for the 4PL transaction centre

Sl. No.	Input Parameters	Output Parameter
1.	Projected Quantity Accepted in Numbers	Combined Revenue Spend in USD
2.	Projected Weight Shipped in kg	--

Moreover, datasets of suppliers and LSPs for virtual mergers have been prepared with reference to cluster-wise category attained from the recommended *Make-Shift* methodology. Moving forward, arriving at cross-segment virtual mergers has been demonstrated in the next section.

5.3.2 Integration of Cross-Segment Virtual Mergers

In this section, cross-segment integration option for all the clusters has been depicted in fig. 5.13.

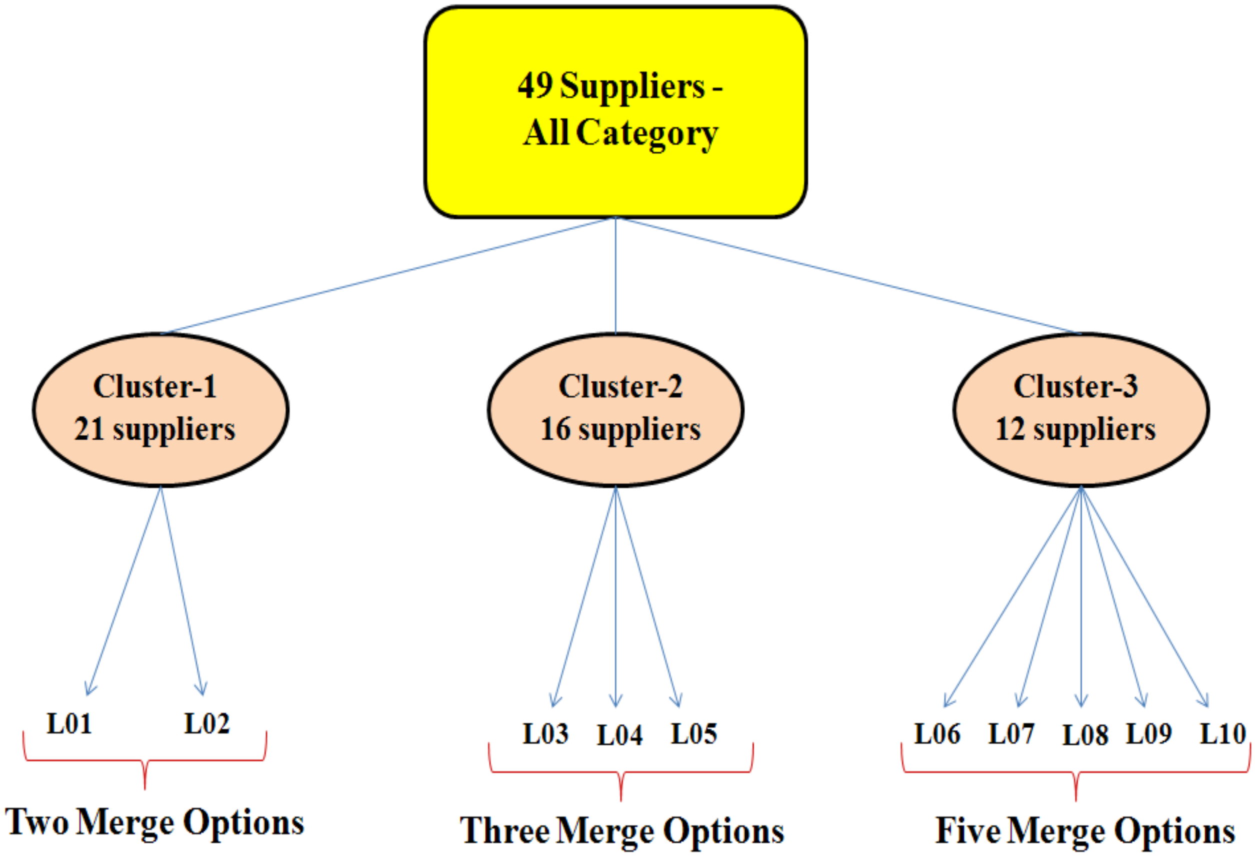


Figure 5. 13 Cross-segment virtual merger options

From the above figure, two merger options has been considered for cluster-1 analysis as shown in table 5.4 along with their category. In this cluster, the cross-segment merger has been carried out between suppliers and LSPs (L01 and L02). Similarly, three merger options for cluster-2 and five merger options for cluster-3 has been considered for analysis as depicted in fig. 5.13. However, these cross-segment formulations have been integrated from the available dataset to model the transaction centre. The category column mentioned in table 5.4 deals with cluster results obtained from the analysis stage in chapter-4. Thus, the proposed *Make-Shift* methodology outcomes obtained through SC analytics under MCDM criteria has been viewed for model development. In the next section, arriving at optimal merger combination has been illustrated from the virtual merger set.

Table 5. 4 Cross-segment integration option for cluster-1

Sl. No.	Merge 1	Merge 2	Category
1	Me1C01L01	Me2C01L02	1
2	Me1C04L01	Me2C04L02	2
3	Me1C05L01	Me2C05L02	2
4	Me1C07L01	Me2C07L02	1
5	Me1C09L01	Me2C09L02	4
6	Me1C13L01	Me2C13L02	4
7	Me1C14L01	Me2C14L02	3
8	Me1C15L01	Me2C15L02	4
9	Me1C19L01	Me2C19L02	3
10	Me1C20L01	Me2C20L02	4
11	Me1C26L01	Me2C26L02	4
12	Me1G20L01	Me2G20L02	4
13	Me1M05L01	Me2M05L02	1
14	Me1M09L01	Me2M09L02	1
15	Me1M19L01	Me2M19L02	2
16	Me1M24L01	Me2M24L02	3
17	Me1M28L01	Me2M28L02	3
18	Me1M30L01	Me2M30L02	3
19	Me1S21L01	Me2S21L02	1
20	Me1S29L01	Me2S29L02	4
21	Me1S30L01	Me2S30L02	4

5.3.3 Determination of Optimal Cross-Segment Merger

In order to accomplish OE, θ and SE has been computed using input oriented categorical model (see Equation 5.11). As an illustration, input and output datasets of cluster-1 cross-segment integration 'merger-1' and 'merger-2' has been collated to apply DEA models. From this, θ^{*}_{CCR} and θ^{*}_{BCC} has been calculated separately to estimate SE for cluster-1 cross-segment merger-1 and 2 as shown in table 5.5.

Table 5. 5 SE scores of cluster-1 cross-segment mergers

Sl. No.	DMU	Merger-1 with L01			Merger-2 with L02		
		θ^{*}_{CCR}	θ^{*}_{BCC}	SE	θ^{*}_{CCR}	θ^{*}_{BCC}	SE
1	C01	0.2042	0.9999	0.2042	0.0901	0.9999	0.0901
2	C04	0.7314	1	0.7314	0.5116	0.9999	0.5116
3	C05	0.5900	1	0.5900	0.5044	1	0.5044
4	C07	0.7693	1	0.7693	0.5965	1	0.5965
5	C09	0.5583	0.9999	0.5584	0.5038	1	0.5038
6	C13	1	1	1	1	1	1
7	C14	0.6152	1	0.6152	0.1944	1	0.1944
8	C15	0.5729	1	0.5729	0.4163	0.9999	0.4163
9	C19	1	1	1	1	1	1
10	C20	0.5698	0.9999	0.5699	0.4008	0.9999	0.4008
11	C26	0.5487	0.9999	0.5487	0.4571	0.9999	0.4571
12	G20	0.9472	0.9999	0.9473	0.9264	1	0.9264
13	M05	0.1703	1	0.1703	0.0772	1	0.0772
14	M09	0.9832	1	0.9832	0.5756	1	0.5756
15	M19	0.0699	1	0.0699	0.0241	0.9999	0.0241
16	M24	0.2637	0.9999	0.2637	0.1501	0.9999	0.1501
17	M28	0.8123	0.9999	0.8123	0.6241	0.9999	0.6241
18	M30	0.5387	0.9999	0.5387	0.3228	0.9999	0.3228
19	S21	1	1	1	1	1	1
20	S29	0.5111	0.9999	0.5111	0.4159	1	0.4159
21	S30	0.8389	0.9999	0.8389	0.6768	0.9999	0.6768

In the next step, based on $\varsigma*$ and $\phi*$, $\alpha*$ for the cross-segment mergers has been calculated (equation 5.9) and reported in table 5.6.

Table 5. 6 α^* scores of cluster-1 mergers

Sl. No.	DMUs	Merge 1 α^* L01	Merge 2 α^* L02
1	C01	0.2367	0.1965
2	C04	0.2199	0.2004
3	C05	1	1
4	C07	0.4407	0.4289
5	C09	0.1783	0.1649
6	C13	0.5482	0.5354
7	C14	1	1
8	C15	0.5163	0.4406
9	C19	0.7349	1
10	C20	0.6768	0.6063
11	C26	0.2590	0.2391
12	G20	0.6608	0.6377
13	M05	0.5076	0.4485
14	M09	1	1
15	M19	1	1
16	M24	1	1
17	M28	1	1
18	M30	1	1
19	S21	1	1
20	S29	0.2273	0.2080
21	S30	1	1

In order to critically analyse the mergers from cost perspective, it has been considered apt to summarise α^* scores for all the cross-segment mergers. Besides, this helps the coordinator of 4PL transaction centre to look at merger gains in individual clusters from financial perspective. Correspondingly, SE and α^* calculations have been carried out for cluster-2 and 3 cross-segment mergers. Moving forward, individual OE scores with all the possible merger options has been reported in table 5.7 for cluster-1 mergers.

Table 5. 7 OE scores of cluster-1 mergers

Sl. No.	DMUs	Merge 1 OE L01	Merge 2 OE L02
1	C01	0.0483	0.0177
2	C04	0.1609	0.1025
3	C05	1	1
4	C07	0.3391	0.2559
5	C09	0.0995	0.0831
6	C13	0.5482	0.5354
7	C14	0.6152	0.1944
8	C15	0.2958	0.1834
9	C19	1	1
10	C20	0.3857	0.2430
11	C26	0.1421	0.1093
12	G20	0.6259	0.5908
13	M05	0.0864	0.0346
14	M09	0.9832	0.5756
15	M19	0.0597	0.0198
16	M24	0.1529	0.0763
17	M28	0.5951	0.4029
18	M30	0.5387	0.3228
19	S21	1	1
20	S29	0.1162	0.0865
21	S30	0.7084	0.5297

To select the optimal combination, merger with highest OE score has been viewed with reference to individual suppliers and LSPs. For instance, ‘M28’ supplier yields the maximum OE with merger-1 option inferring that it should be integrated with ‘L01’ LSP. At the same time, an average OE for all the clusters has been signified in fig. 5.14 for different cross-segment merger options.

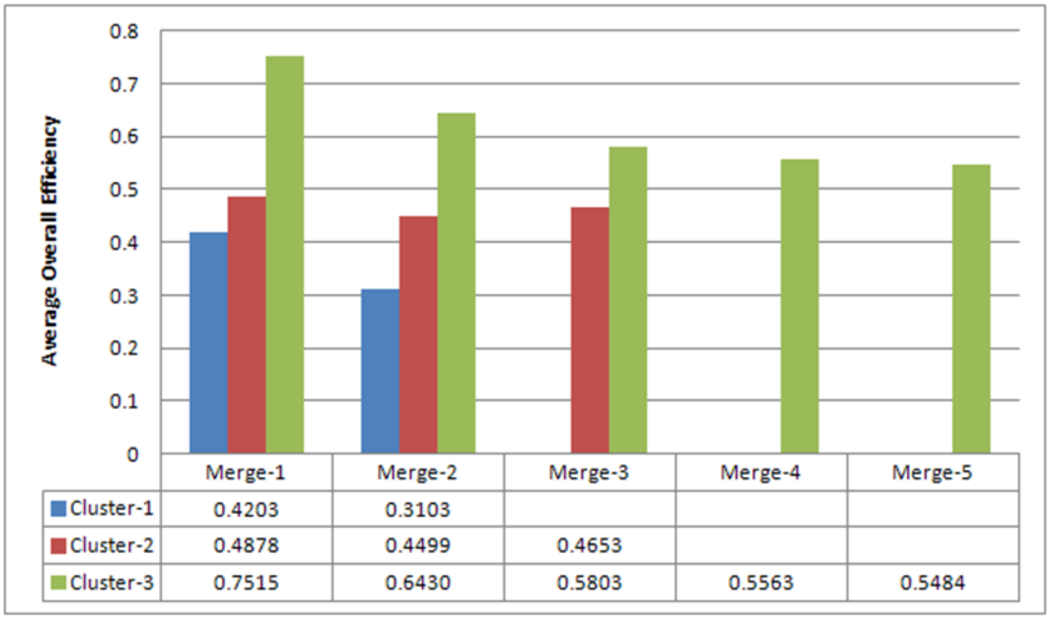


Figure 5. 14 Average OE scores of the clusters

Figure 5.15 exhibits the radar chart of cluster-1 mergers with optimal cross-segment integration options.

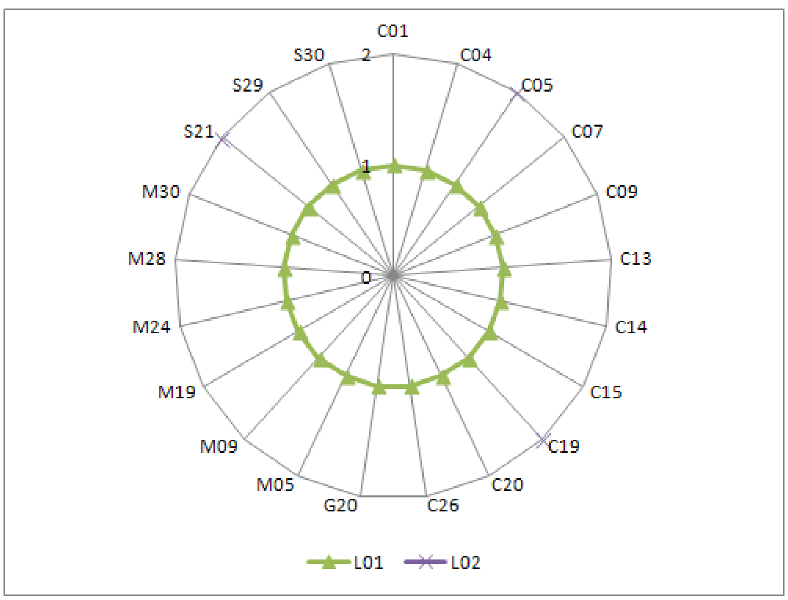


Figure 5. 15 Optimal integration option for cluster-1 mergers

The radar chart has been utilised to interpret cross-segment integration of suppliers and LSPs for selecting the optimal mergers. Here, different categories of suppliers divide the outer circle in to various sections. Similarly, radar chart is further classified into sub-circles based on the number of merger options available. Further, these sub-circles have been numerically represented (For example: 1, 2) covering all the merger options. In first tier of the proposed 4PL cross-segment integration framework, maximum OE score of the virtual mergers has been utilised to derive operating standards. In cluster-1, trading partners reported in table 5.2 divides the circle in to 21 sections (C01 to S30) as depicted in the above figure. The radar chart is further classified in to two sub-circles since cluster-1 has L01 and L02 merger options. Considering highest OE scores across the virtual mergers in table 5.7, optimal cross-segment integration standards has been derived for integrating suppliers and LSPs. For example, results revealed integration of C01 supplier with L01 LSP for attaining maximum merger gain. Similarly, interpretation for other mergers can be reported. In principle, representation of the cross-segment integration in the proposed 4PL transaction centre has been put forward from performance perspective. Likewise, the optimal cross-segment integration options for cluster-2 and 3 mergers have been derived.

Tie-situation has been observed during the selection of optimal OE combinations across all the clusters. In order to address tie-situation in the merger options, the second tier of the proposed cross-segment integration framework has been looked from cost orientation. For instance in cluster-2, 'C23' has the same OE score with all the LSPs (L03, L04 and L05). In such cases, cost factor of these mergers has been considered as a second tier approach. Firstly, the cost inefficiencies from individual suppliers/LSPs has been removed using input oriented categorical model separately (expression 5.11). By integrating two different categories of trading partners into a merger (supplier and LSP), input cost has been computed as follows:

$$v = v_1^* + v_2^* \qquad \text{……………} \ (5.38)$$

From the attained v and corresponding outputs y_i, $C(y_{1o}, y_{2o})$ has been obtained through LPP formulation (expression 5.17). Further, the solution of $C(y_{1o},y_{2o})$ has been compared with all possible merger options available in the clusters. Finally, the least merger cost has been selected. By applying the cost-merger formulation, the enhanced optimal integration option has been derived as shown in figure 5.16, thus, final operating standards has been derived. In this way, tie-situation has been addressed using cost-merger model by selecting 'merger-2' as an integration option in all three cases of cluster-1 mergers. In particular, the operating standards envisage the best cross-segment integration option for merging suppliers and LSPs.

Cluster1	Merged Cost in USD	Cluster1	Merged Cost in USD
Me1C05L01	173194	Me2C05L02	163500
Me1C19L01	29110	Me2C19L02	19416
Me1S21L01	849565	Me2S21L02	839871

Sl. No.	Cluster1 V-RTS	Overall Efficiency Merge1 (L01)	Overall Efficiency Merge2 (L02)
1	C01	0.0483	0.0177
2	C04	0.1609	0.1025
3	C05	1	1
4	C07	0.3391	0.2559
5	C09	0.0995	0.0831
6	C13	0.5482	0.5354
7	C14	0.6152	0.1944
8	C15	0.2958	0.1834
9	C19	1	1
10	C20	0.3857	0.2430
11	C26	0.1421	0.1093
12	G20	0.6259	0.5908
13	M05	0.0864	0.0346
14	M09	0.9832	0.5756
15	M19	0.0597	0.0198
16	M24	0.1529	0.0763
17	M28	0.5951	0.4029
18	M30	0.5387	0.3228
19	S21	1	1
20	S29	0.1162	0.0865
21	S30	0.7084	0.5297

Sl. No.	Cluster1 V-RTS	Overall Efficiency Merge1 (L01)	Overall Efficiency Merge2 (L02)
1	C01	0.0483	0.0177
2	C04	0.1609	0.1025
3	C05	1	1
4	C07	0.3391	0.2559
5	C09	0.0995	0.0831
6	C13	0.5482	0.5354
7	C14	0.6152	0.1944
8	C15	0.2958	0.1834
9	C19	1	1
10	C20	0.3857	0.2430
11	C26	0.1421	0.1093
12	G20	0.6259	0.5908
13	M05	0.0864	0.0346
14	M09	0.9832	0.5756
15	M19	0.0597	0.0198
16	M24	0.1529	0.0763
17	M28	0.5951	0.4029
18	M30	0.5387	0.3228
19	S21	1	1
20	S29	0.1162	0.0865
21	S30	0.7084	0.5297

Figure 5. 16 Second tier approach to select integration option for cluster-1 mergers

Similarly, final operating standards have been deduced for cluster-2 and 3 mergers as depicted in fig. 5.17 and 5.18 respectively.

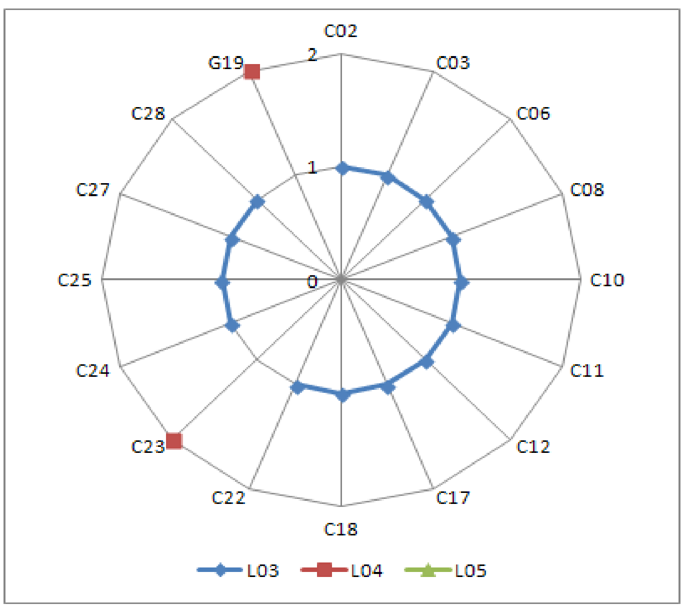


Figure 5. 17 Final cross-segment integration option for cluster-2 mergers

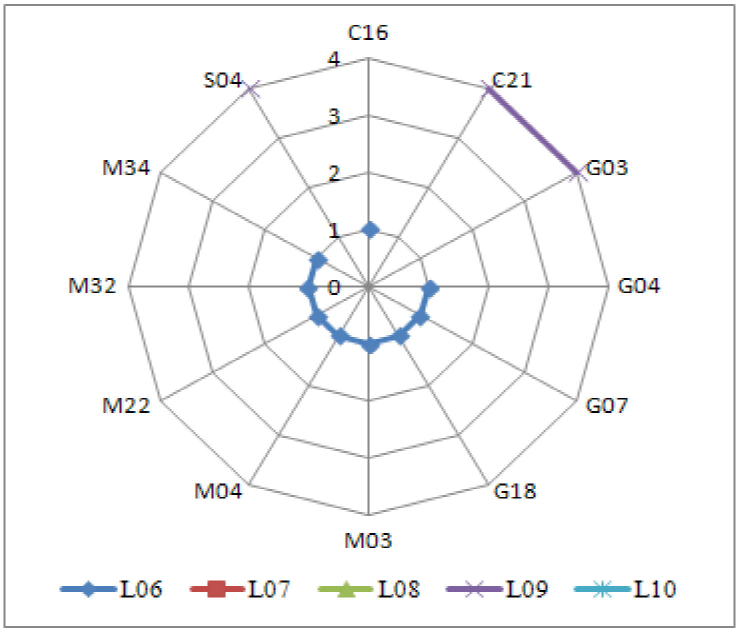


Figure 5. 18 Final cross-segment integration option for cluster-3 mergers

Cluster-2 has 16 sections (C02 to G19) as depicted in table 5.2 and three merger options (L03 to L05) for conducting cross-segment integration. In the same way, cluster-3 has 12 sections (C16 to S04) as reported in table 5.2 and five merger options (L06 to L10). Moreover, these radar charts represent the dashboard framework to manage cross-segment integration in the 4PL transaction centre. In summary, the final operating standards for cross-segment integration have been suggested by virtue of the proposed two-tier approach. This helps the coordinator of transaction centre to optimally balance the 4PL set up from operations perspective. It has been observed that few LSPs remain unutilised in cluster-2 and 3 optimal integration options. The details of these unutilised LSPs have been reported in table 5.8. Therefore, the developed model suggests removing unutilised LSPs from the transaction centre pool signifying *best of breed* approach.

Table 5. 8 Details of unutilised LSPs

Sl. No.	Description	Unutilised LSPs
1	Cluster-2	L05
2	Cluster-3	L07 L08 L10

5.3.4 Evaluation Results and Discussions

Model evaluation of the transaction centre has been carried out through merger cost comparison between the legacy and the proposed model. Figure 5.19 shows 18% of merger cost savings for cluster-1 mergers. Likewise, 39% and 43% of merger cost savings have been reported for cluster-2 and 3 mergers respectively. In summary, 33% of average merger cost savings has been obtained from the recommended transaction centre model.

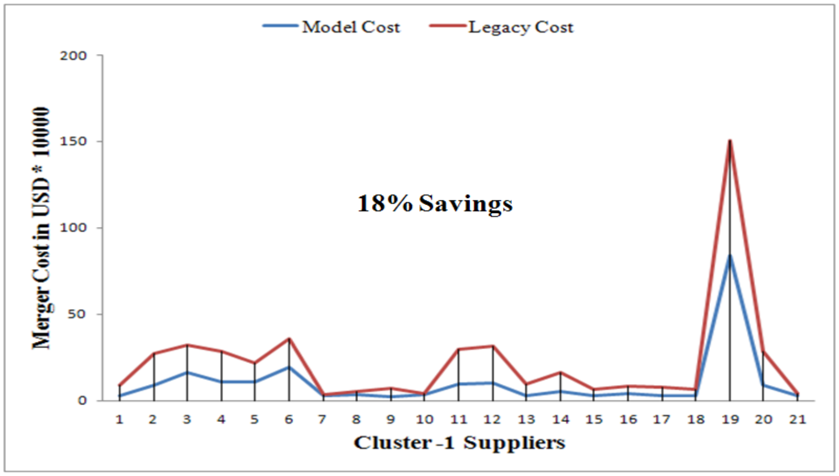


Figure 5. 19 Cluster-1 merger cost comparison

In the same way, individual value plot of the merger cost against their respective group has been plotted in fig. 5.20. It has been observed that mean and variance in the suggested model has been consistent compared to the legacy situation.

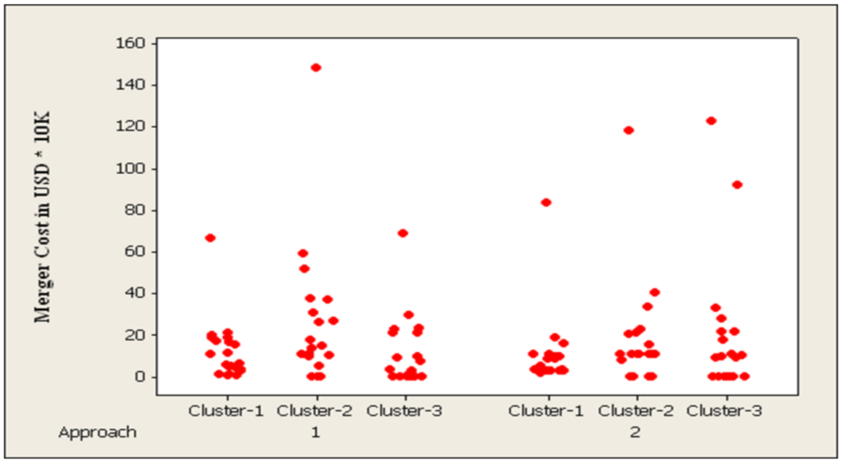


Figure 5. 20 Individual value plot of clusters

Therefore, the obtained results have been considered effective compared to legacy situation with regard to cluster-1 mergers. Likewise, cluster-2 and 3 mergers have been confirmed to the distribution fit accordingly. Moving forward, adequacy of the proposed model has been assessed through ρ_c. Figure 5.21 portrays consolidated ρ_c score for all the clusters.

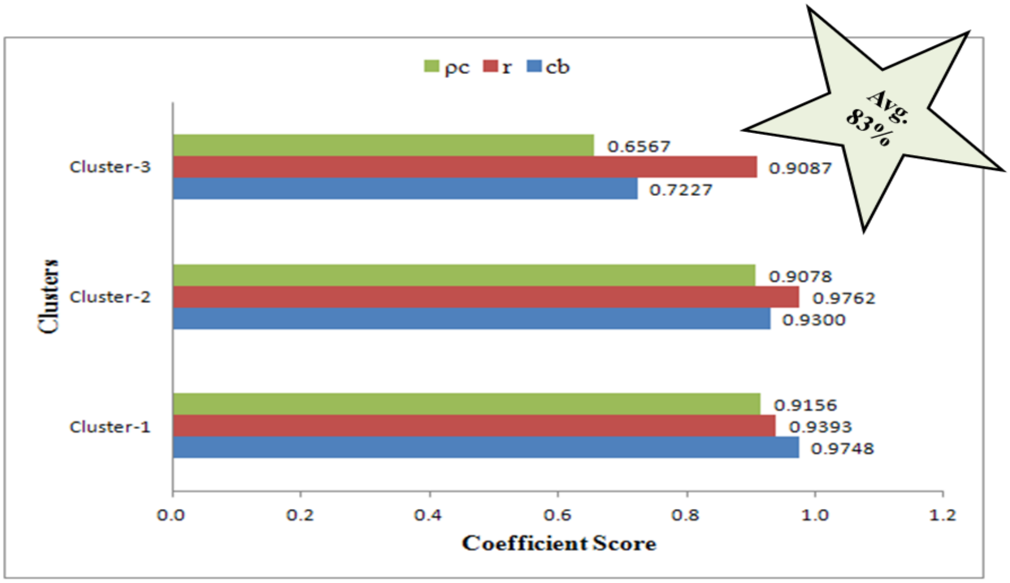


Figure 5. 21 Consolidated ρ_c score

At least 83% of the model predicted values achieve precision (94% to 97%) and accuracy (72% to 96%) simultaneously. Further, the variation proportion of the fitted line has been estimated through MEF statistics across all the clusters as shown in fig. 5.22. 85% of variation has been captured through MEF statistics, thus, making the intended model sustainable.

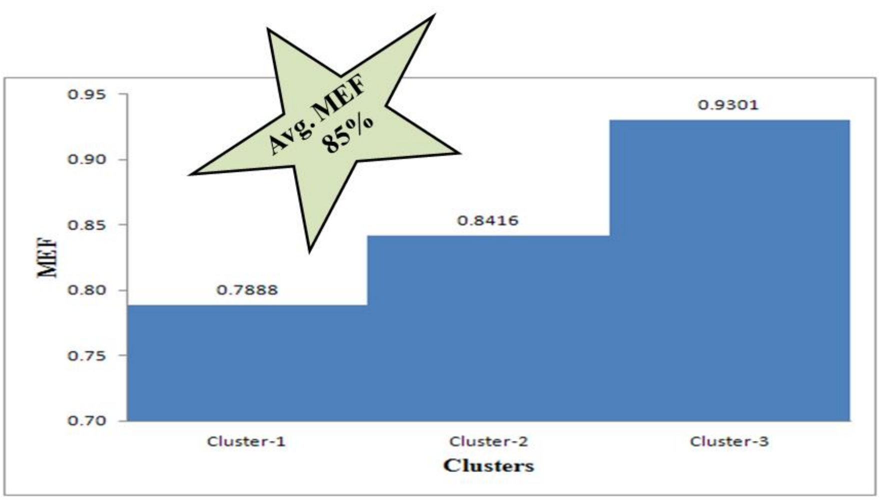


Figure 5. 22 MEF statistics of the proposed model

In the next stage, evaluation of the transaction centre model has been carried out through data variation by splitting input-output data into training and verification dataset. The training dataset has been referred as Model-1 and verification dataset has been referred as Model-2. Considering the datasets (segment-1), the developed multi-stage performance evaluation framework has been applied individually (see chapter 4). Figure 5.23 portrays DEA efficiency scores for Model-1 and 2 for all the trading partners under both RTS conditions. However, the consistent DEA scores have been depicted for both models at 95% CI.

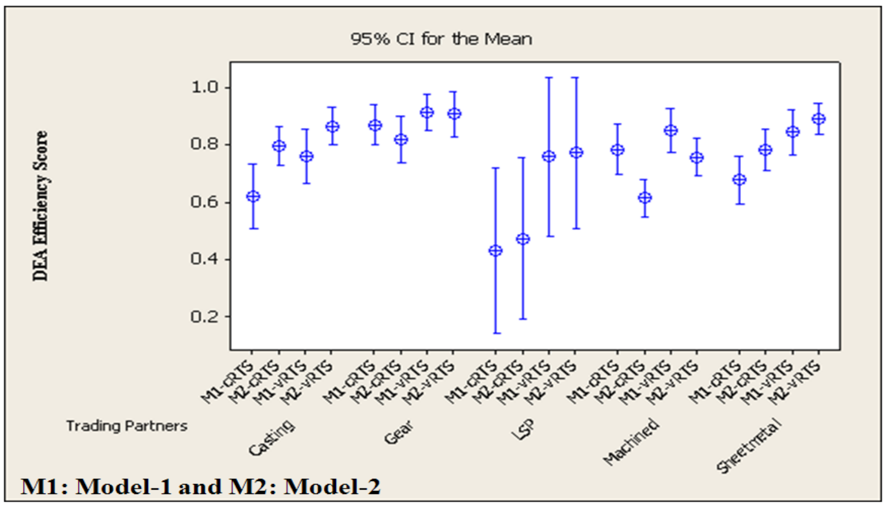


Figure 5. 23 Interval distribution of DEA scores

In addition, individual output projections of suppliers performance has been represented in fig. 5.24.

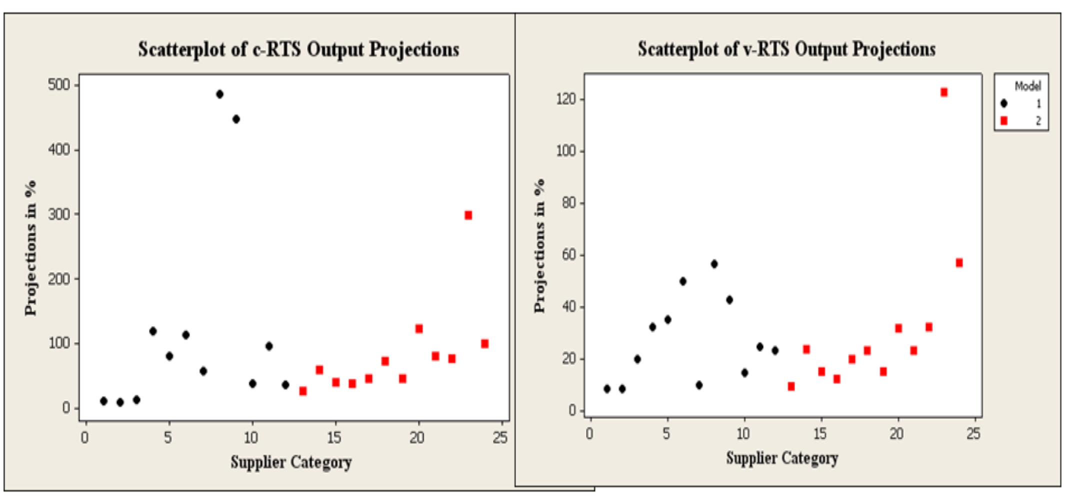


Figure 5. 24 Scatter plot considering three outputs per supplier

Both models yielded similar results substantiating consistency in the proposed performance evaluation framework. Conversely, the order of supplier category in the scatter plot starts with gears, castings, sheet metal, and turned and machined suppliers accordingly. An attempt to decompose the dynamic efficiency of Model-1 and 2 has been executed for gears supplier utilising matrix plot. It has been observed that efficiency plot of both the models correspond significantly with data variation as depicted in fig. 5.25.

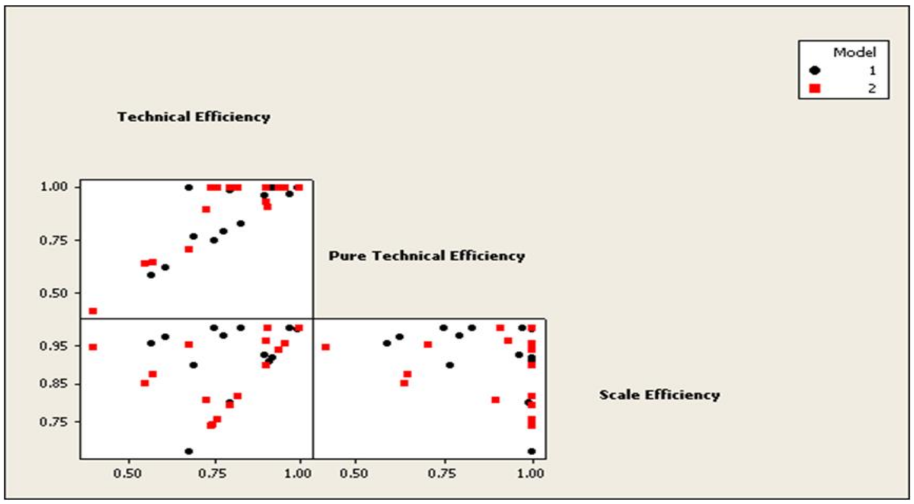


Figure 5. 25 Efficiency decomposition of Model-1 and 2

To critique inter and within DMU evaluation of Model-1 and 2, bi-lateral DEA comparison has been carried out to validate the evaluation framework. Figure 5.26 signify the results of bi-lateral comparison for Model-1 and 2 with respect to different criteria.

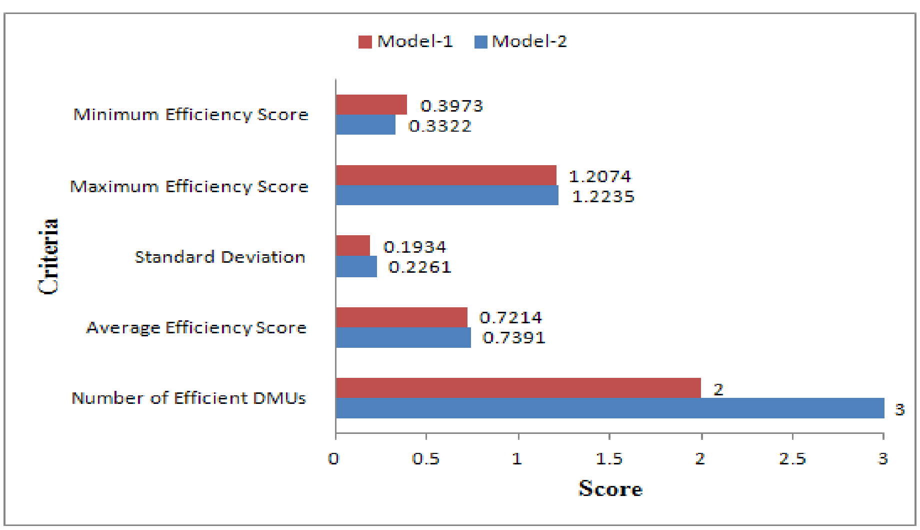


Figure 5. 26 Bilateral DEA analysis summary

This technique envisages that each individual trading partner in Model-1 has been evaluated with respect to trading partners of Model-2 and vice versa. Since, the region of θ has been expanded; critical discrimination to verify distributions between models has been conducted. It has been observed that both the models yielded similar results through data variation with mean DEA efficiency ranging between 72% to 74%. In addition, the above claim has been substantiated using non-parametric statistical test. For that reason, Wilcoxon-Mann-Whitney rank sum test has been executed to identify significant differences between the two models. The null $\mathbf{H_o}$ and alternative $\mathbf{H_1}$ hypothesis has been formulated at significance level $\alpha = 5\%$ as follows:

$\mathbf{H_o}$**:** There is no significant frontier shift between Model-1 and 2, thus, belong to the same population

$\mathbf{H_1}$**:** There is a significant frontier shift between Model-1 and 2, thus, do not belong to the same population

On the other hand, rank sum statistics has been computed using expression (4.26) considering gears supplier with data variation (Model-1 and 2). From the calculated and the critical Wilcoxon *T-statistics*, the $\mathbf{H_o}$ has been accepted at $\alpha = 5\%$. Therefore, Model-1 follows the same distribution of efficiency scores with that of Model-2 and statistically significant.

Subsequently, the evaluation of the proposed transaction centre model has been carried out with regard to consistency and adequacy (segment-2). In particular, the consistency of the transaction centre model has been assessed using OE parameters. Figure 5.27 portrays the data distribution of Model-1 and 2 for cluster-1 mergers. Nonetheless, consistency in merger gains has been observed with OE scores varying between 2% to 17%. Subsequently, average OE comparisons has been computed across all the clusters as depicted in fig. 5.28 and results yielded similar values. In the next step, the proposed model adequacy has been examined using decomposition of MSEP. Moreover, this decomposition indicates different patterns in the error of prediction for Model-1 and 2 respectively.

Hence, it has been inferred that:

- 53% of errors have been due to lack of correlation between the random errors for both models in cluster-1

- 45% of errors have been due to mean bias error for both models in cluster-2
- Slope bias accounted for 64% of errors in Model-1 and 53% of errors accounted due to lack of correlation between random errors for Model-2 in cluster-3

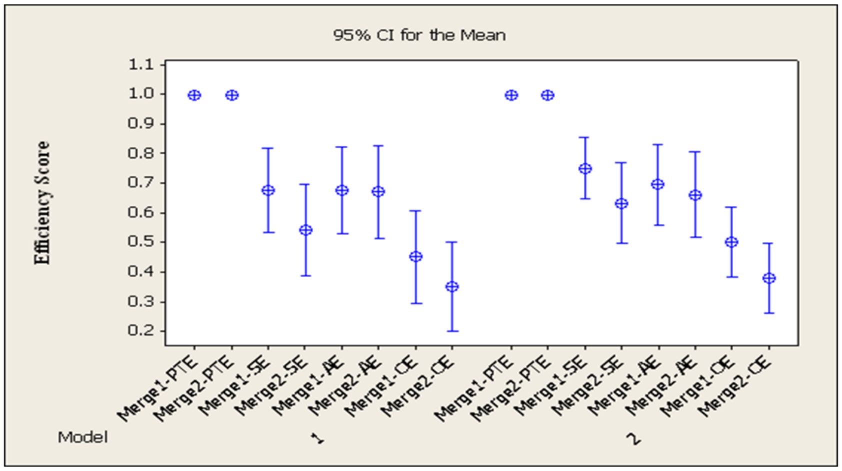


Figure 5. 27 Data distribution of cluster-1 mergers

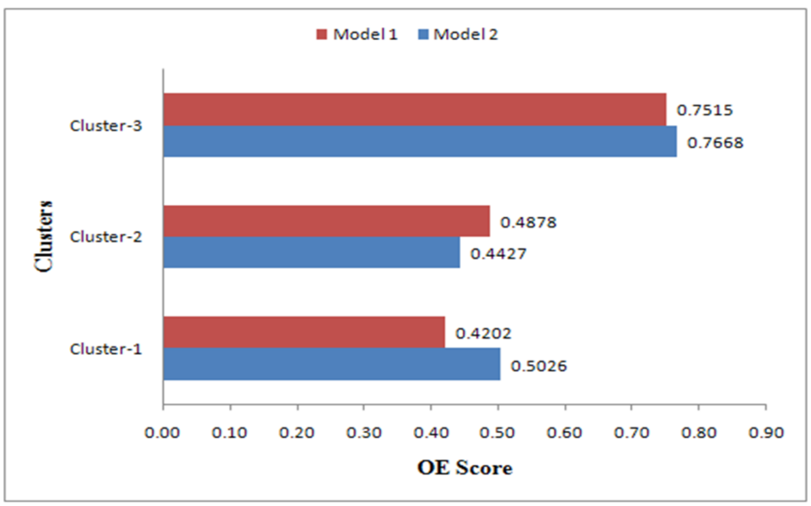


Figure 5. 28 Average OE comparisons

Here, cluster-1 and 2 mergers signify same pattern of error decomposition; cluster-3 portrays different pattern of error decomposition. This situation has been attained due to the large spread of cluster-3 mergers considering entire India except Tamil Nadu, Karnataka and Maharashtra states. Consequently, the evaluation of the optimal mergers obtained from the suggested model has been critically analysed. Figure 5.29 indicates the optimal merger combination of cluster-1 mergers attained through data variation for Model-1 and 2 respectively.

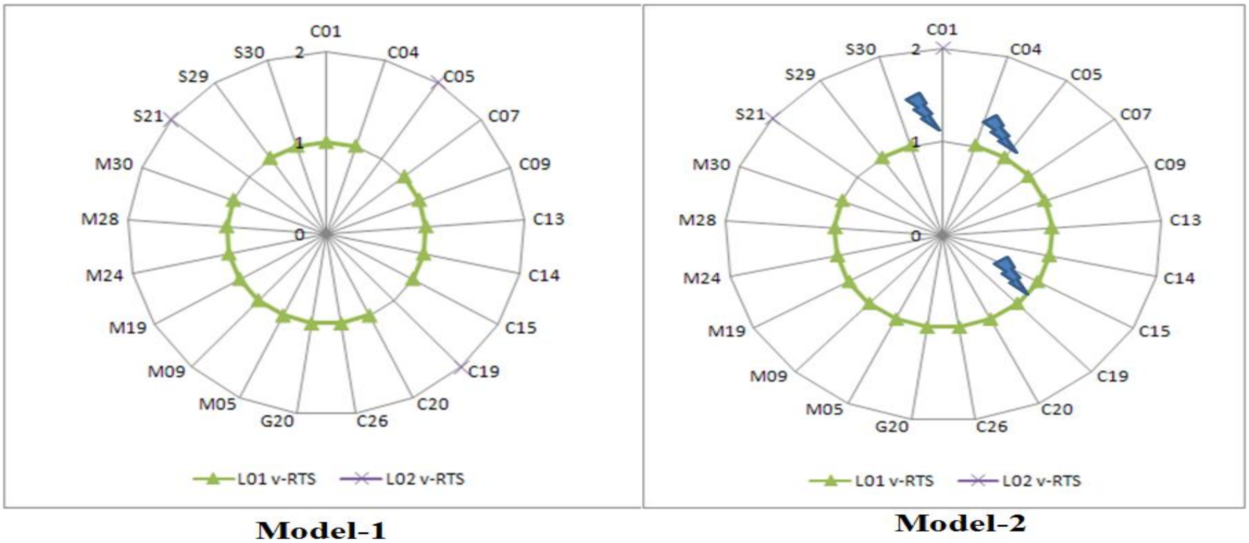


Figure 5. 29 Optimal merger combinations of cluster-1

It has been found that three out of 21 mergers suggest differences between Model-1 and 2 in the optimal merger selection. In order to address this issue, system efficiency model has been utilised to validate the attained merger efficiencies. Here, Model-1 and 2 dataset have been considered as system-A and B correspondingly. For instance, the mergers with difference in the optimal merger options (C01 and C05) have been considered to select minimum efficiency. Figure 5.30 depicts the system efficiency comparison with respect to OE for both merger options (L01 and L02).

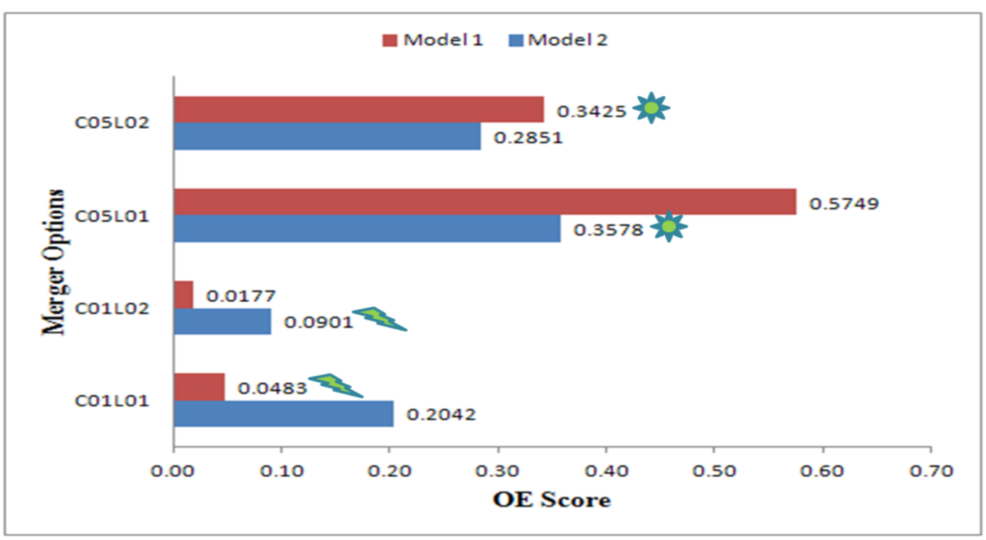


Figure 5. 30 System efficiency comparisons of C05 and C01 DMUs

Thus, the final optimal merger combination has been reported in fig. 5.31. Consequently, this technique has led to the original merger option attained by Model-1.

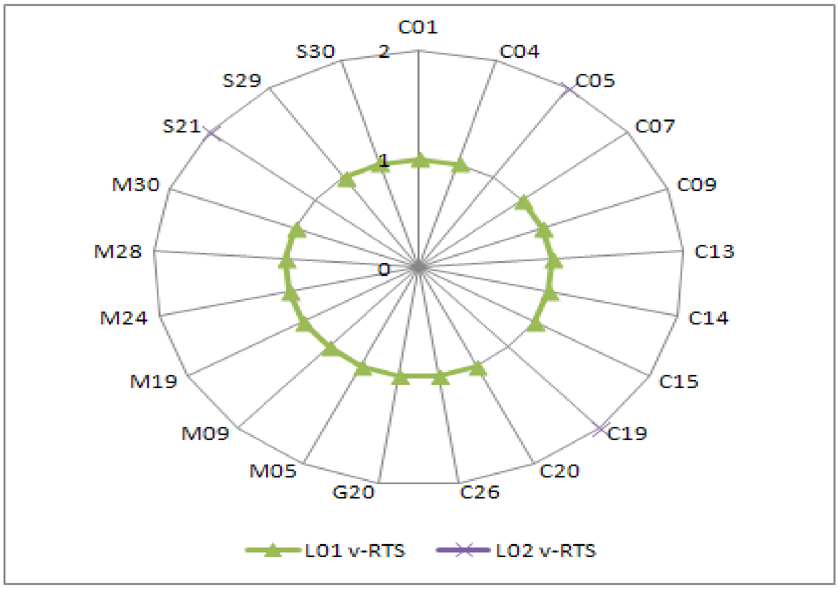


Figure 5. 31 Cross-validated final merger combination of cluster-1

Hence, the proposed model yield similar results for selecting the optimal mergers across trading partners (suppliers and LSPs) through data variation. In the next section, stability and sensitivity analysis for the recommended model has been carried out.

5.3.5 Model Verification and Validation

In this section, stability of the derived operating standards from cross-segment integration (suppliers and LSPs) in the proposed 4PL transaction centre has been assessed. Window analysis has been performed considering tier-1 and 2 situations for cluster-1 mergers as shown in fig. 5.32. Furthermore, tie-situation for castings supplier (C05 and C19) has been critically analysed with two merger options (L01 and L02).

The following initial data has been considered:

Number of DMUs n = 11

Number of months $k = 9$

Length of Window $l_w = 3$ ($l_w \leq k$)

Number of Windows $N_w = k - l_w + 1 = 7$

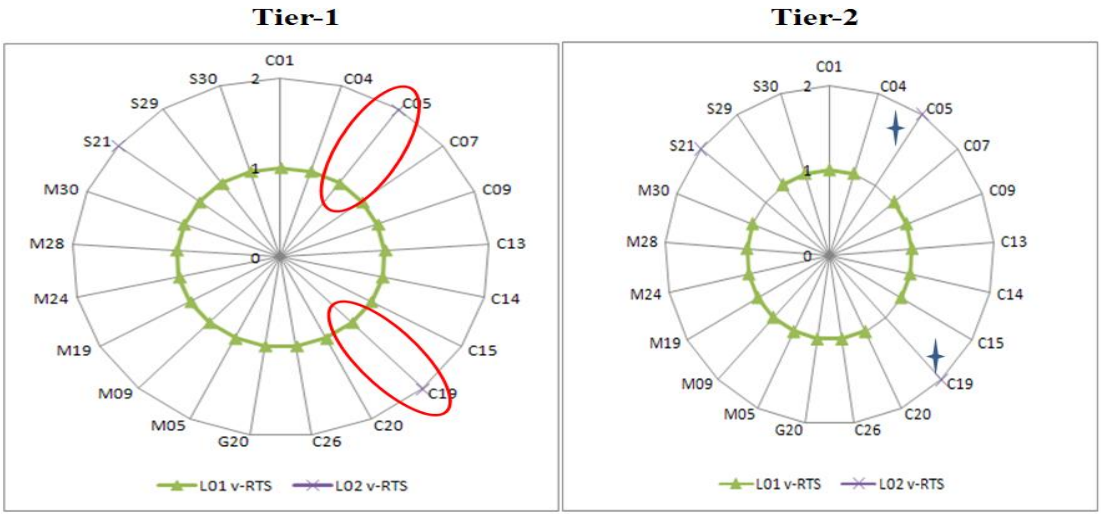


Figure 5. 32 Tier-1 and 2 situations from the transaction centre model of cluster-1 mergers

Moving forward, window analysis efficiency scores for merge-2 C05L02 combination has been depicted as follows:

Month	1	2	3	4	5	6	7	8	9
Me2C05L02	0.6157	1	0.7483						
		1	0.7140	1					
			0.6194	0.8921	1				
				0.8201	1	1			
					1	1	0.6590		
						1	0.7882	1	
							0.7895	1	0.8629

Figure 5. 33 Window analysis of Me2C05L02 merger combination

Column view portrays the stability and row examination signifies the variation trend for different time periods. Figure 5.34 implies variation and stability plot for C05 supplier with cluster specific LSPs respectively. In the similar way, efficiency calculation for other merger combinations has been carried out. It has been observed from the variation plot that merger of suppliers with L01 (merger-1) offers consistent trend compared to L02 (merger-2). Further, the trend behaviour matches the recommended model results obtained from tier-1 analysis.

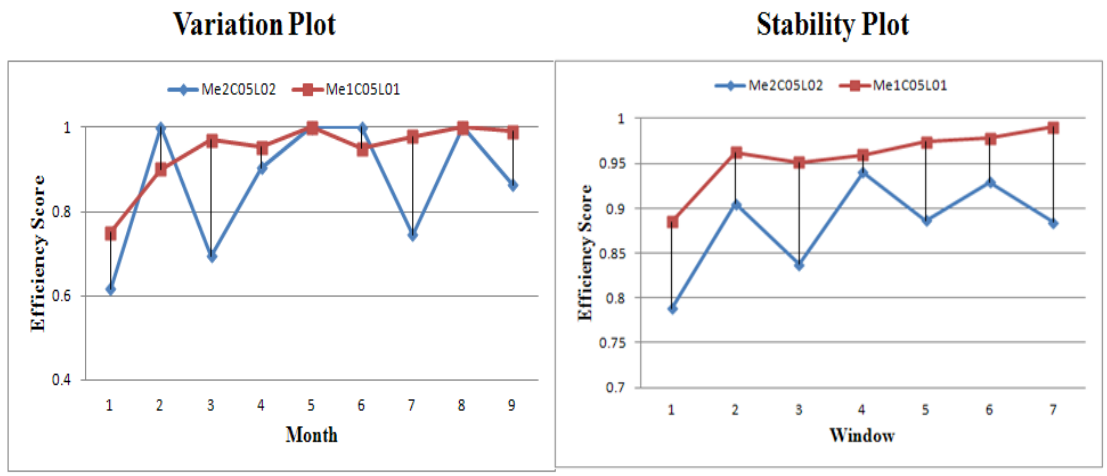


Figure 5. 34 Variation and stability plot of C05 supplier

On the other hand, the stability plot infers higher average efficiency scores with L01 merger across all the windows compared to L02. In addition, the efficiency score decreases whenever tier-2 approach has been considered to address tie-situations. Thus, merging suppliers with L01 has been recommended to get optimal merger combination. In this way, stability of the proposed transaction centre has been verified through data variation.

Subsequently, sensitivity analysis has been performed by estimating stability radius for the individual optimal mergers across all the clusters. Abri's *et al.* (2009) framework has been applied to OE parameters represented in expression (5.8) which consists of PTE, SE and AE. Figure 5.35 portrays the stability region of cluster-1 mergers without and with data variation.

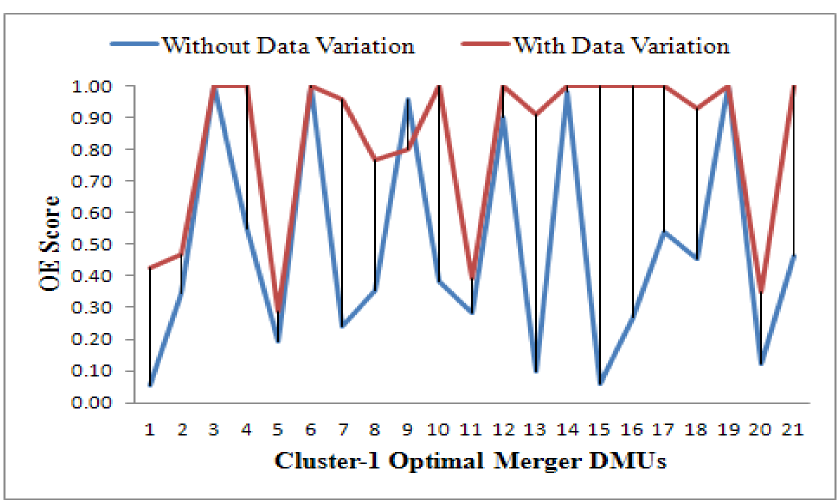


Figure 5. 35 Sensitivity analysis of cluster-1 mergers

Here, sensitivity analysis has been implemented individually to OE parameters of optimal mergers to estimate δ^* using expression (5.29a) or (5.29b) based on efficiency classification. Accordingly, OE with data variation has been estimated for all the clusters. In addition, OE without data variation has been collated and comparison between OE scores has been implemented. In order to verify the OE parameters effect, decomposition through main effects plot has been depicted in fig. 5.36 for without and with data variation condition.

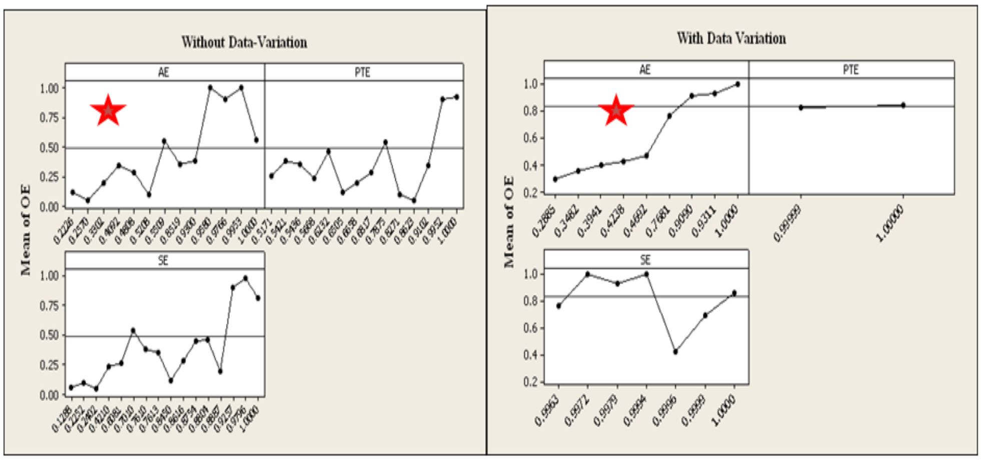
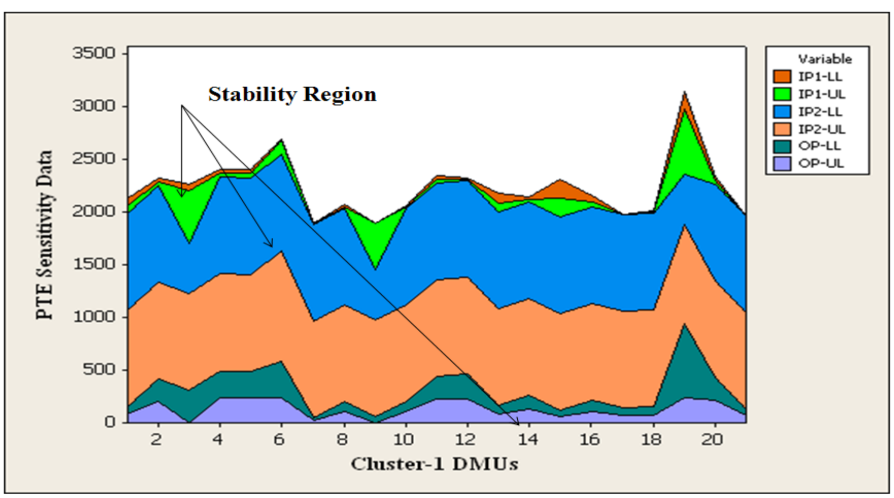


Figure 5. 36 OE decomposition effects plot of cluster-1 mergers

It has been observed that AE effect on OE scores has been seemingly large for without and with data variation condition. Therefore, the 4PL coordinator can analyse direction towards increasing the OE score by balancing the cost parameters. Figure 5.37 shows the stability region for PTE parameter.



LL: Lower Limit, UL: Upper Limit, IP_i = Input i, OP_i = Output i

Figure 5. 37 PTE stability radius for cluster-1 mergers

Consequently, C05L01 merger in fig. 5.38 has been examined by applying scatter plot of panel variable with different PTE sensitivity.

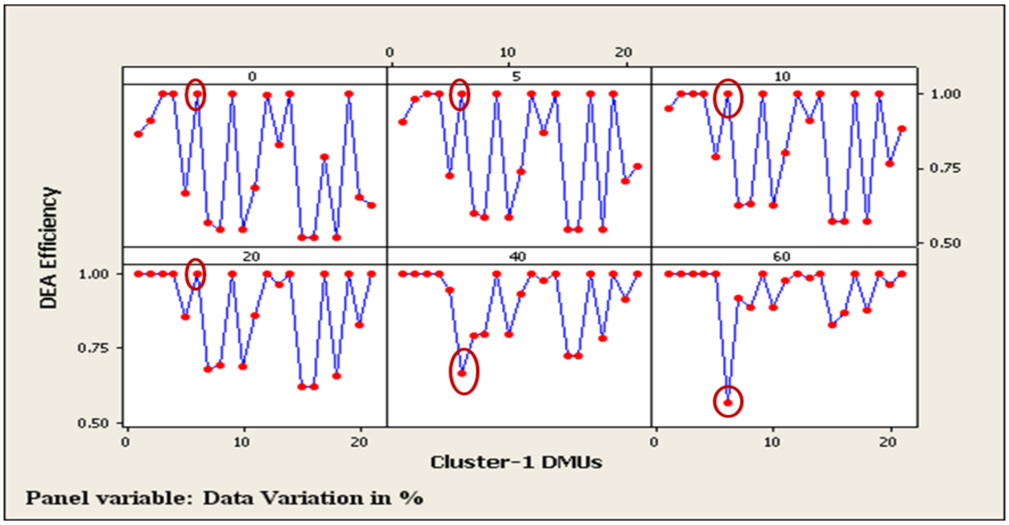


Figure 5. 38 Stability plot with panel data variation for C05L01 merger

It has been demonstrated that PTE score retains efficiency status till 20% and gradually loses efficiency status as and when data variation (%) increases signifying stability and non-stability region. Similarly, stability region for other individual OE parameters has been estimated. Likewise, sensitivity analysis has been performed to cluster-2 and 3 optimal mergers. In order to validate the difference among sensitivity dataset of OE scores (without and with data variation), Wilcoxon signed-rank test has been carried out. Further, the ranks of these differences have been viewed to arrive at Wilcoxon *T-statistic*. It has been observed that distribution without and with data variation has been different between the OE scores with respect to median difference (see Appendix C.1).

5.4 Conclusions and Summary

This chapter contributes to the literature in numerous ways. 4PL transaction centre has been modelled, implemented and validated to become the backbone of network organisation. In this thesis, Bogetoft and Wang's (2005) production economics integration model has been extended from conventional similar-segment mergers to cross-segment mergers to quantify the optimal merger gain. The proposed model can comprehensively integrate the improved competencies of third parties with analytical ability. More specifically, the developed model can deal with a range of virtual mergers and provide operating standards for integrating cross-segment trading partners. Therefore, a holistic approach has been presented to assist coordinator for assimilating operations process and implementation characteristics for integrating the trading partners.

A novel two tier approach considering performance and cost orientation for carrying out cross-segment integration has been proposed. In first tier, the approach evaluates virtual merger through OE parameters considering technical and cost efficiencies simultaneously. In second tier, the approach signifies optimal merger with least cost combination only in tie-situations. Besides, factors like balancing and minimising transaction costs on the working principles of transaction centre have been addressed to portray broad industry standards. Apart from cost savings, the recommended model facilitates 4PL coordinator to manage cross-segment mergers by arriving at operating standards. Further, sustainability of the intended model has been evaluated through data variation and validated through non-parametric statistics. In addition, the evaluation procedure signifies level of precision and accuracy with regard to the conceived operating standards for mergers. Verification of the transaction centre model has been performed through stability and sensitivity analysis under necessary and sufficient conditions to retain efficiency status of the merger. In summary, the proposed two-tier approach can assist the coordinator to manage 4PL transaction centre optimally. It has been observed that the recommended model selects only *best of breed* trading partners for carrying out cross-segment integration in compliance with 4PL principles.

As an illustration, the transaction centre has been modelled comprising suppliers and LSPs to arrive at optimal integration options in a two tier approach. Mergers with highest OE score with reference to individual supplier and LSPs have been regarded as the optimal cross-segment merger in tier-1. For instance, 'M28' supplier yields maximum OE with merger-1 option inferring that it should be merged with 'L01' LSP. Nonetheless, in case of tie-situation, the second tier approach has been adopted considering merger cost criteria. For example, 'C05' supplier with both merger options (L01 and L02) has been compared with respect to cost merger model. The model signifies 'C05L02' merger as feasible option due to ~ 6% lesser transaction cost. In addition, the proposed approach has been evaluated by means of comparison between model-predicted and legacy merger cost. The empirical result showed 18% to 43% savings from the developed transaction centre. Model adequacy has been assimilated with respect to accuracy and precision. However, it has been observed that accuracy varied between 72% to 96% and precision ranging from 94% to 97% across all the clusters. Further, MEF statistics captured 85% of variation, thus, making the intended model sustainable compared to legacy situation. Also, the proposed model has been evaluated in two segments by splitting the input-output data into training and verification dataset. In segment-1, performance potential of all the outputs in terms of DEA efficiency yielded similar mean efficiency (72% to 74%) and variance (0.19 to 0.22) through bi-lateral comparison. In segment-2, transaction centre with data variation has been assessed through OE parameters for consistency and decomposition of MSEP for model adequacy. OE score accounted for 2% to 17% variation and decomposition of error prediction revealed similar results. Subsequently, stability of the operating standards has been verified through window analysis with removal and replacement procedures which signified intended model results. Finally, sensitivity analysis has been carried out by deriving stability radius for individual optimal mergers with respect to OE parameters. For instance, sensitivity of 'C05L01' merger with regard to PTE score reveals that the merger retains efficiency status within sensitivity region of 20% data variation and thereafter loses efficiency status accordingly.

In the next chapter, extensions to the developed transaction centre model has been proposed, modelled, implemented and validated. By virtue of these extensions, gap between academic and practical applicability of the intended model has been reduced. In 4PL parlance, the coordinator can critically analyse multi-criteria decisions objectively to manage the transaction centre optimally.

CHAPTER 6: EXTENSIONS TO THE PROPOSED 4PL TRANSACTION CENTRE

6.1 Introduction

In order to make the intended model robust, distinguished features and characteristics are embedded as extensions. In essence, factors like sub-optimal 4PL solutions; incorporating policy decisions and system constraints; grouping trading partners with respect to delivery time are highlighted in this thesis. By suitable extensions, strength and applicability of the transaction centre are demonstrated to solve industry problems. Many researchers and industry managers collectively perceive that mathematical models have to be simple and easy to use for evaluating performance in the real world situation (Wong and Wong, 2008). In this chapter, necessary and sufficient conditions to develop extensions for the 4PL transaction centre are described.

The developed model of 4PL transaction centre deals with *best of breed* DMUs (Fulconis *et al.*, 2007; Richey *et al.*, 2009). Here, DMUs refer to various categories of suppliers and LSPs as trading partners. The model suggests removing unutilised trading partners from the pool of transaction centre before carrying out cross-segment integration. But in the real world situation, the trading partners cannot be discarded and reintegrated like a plug and play solution (Fulconis *et al.*, 2007; Hingley *et al.*, 2011). In order to address this issue, an optimistic procedure to distribute the total business spend (financial value in USD) across all the trading partners is proposed based on the output of the 4PL transaction centre. The word 'optimistic' refers to giving a fair chance for trading partners in order to reach the efficiency frontier using projection details. In addition, flexibility towards incorporating policy decisions and system constraints for selection of trading partners is attempted. Incorporating policy decisions and system constraints assist the 4PL coordinator to provide trade-off possibilities among decisions (Mukhopadhyay and Setaputra, 2006). Lastly, optimal route generation considering delivery time (Shapiro, 2002) for grouping cross-segment DMUs is illustrated for coordinating activities of transaction centre. Each extension illustrates a particular situation in a tiller and tractor manufacturing company. In the next section, assumptions and parameters considered along with the decision variables for executing extensions are discussed.

6.2 Assumptions, Parameters and Models

6.2.1 Assumptions

The assumptions considered for the study include,

- All trading partners agree not to break the game
- Every chain partner has been willing to negotiate with each other through cooperative fair division
- Each DMU has the right to choose preferable maximised weights. Higher the score for a criterion means better the performance of trading partner
- All DMUs agree to share the total spend proportionately based on the ordering mechanism obtained from the coalition of trading partners
- For multi-objective programming model, criteria like late delivery, rejection due to quality issues and average component price of trading partner has been considered
- In combinatorial optimisation methodology, split orders between two or more trucks is not considered
- LSP has unlimited number of trucks at its disposal with capacity of 10,000 kg (10 tons) each. Each truck cannot travel more than 400 km per day as per the company policy

6.2.2 Parameters and Decision Variables

The given parameters include,

- $\boldsymbol{A_{ij}} = a_{ij}$ = Coefficient of Decision Variable
- $\boldsymbol{B_i}$ = Column Vector of g Goals
- D = Late Delivery, %
- D_a = Aggregate Demand Value in USD
- M_i = Trading Partner i
- N_j = Feasible Route j
- P = Average Price of the Component in USD
- P_q = Priority Level
- Q = Number of Priority Level
- R_{ij} = Normalised Score Matrix for i^{th} Player and j^{th} Criteria
- R_q = Rejection Due to Quality Issues, %

- $S = s^+, s^-$ = Slack/Surplus Variables
- S_c = Coalition of Trading Partners
- $\boldsymbol{V_r}$ = Supplier Selection Vector
- $\mathbf{X} = x_{ij}$ = Input for ith Category and jth DMU
- $\mathbf{Y} = y_{ij}$ = Output for ith Category and jth DMU
- *ch( )* = Characteristic Function
- *ch(Sc)* = Coalition with respect to Characteristic Function
- c_{ij} = Cost between Trading Partner i and Feasible Route j
- d_i^+, d_i^- = Deviation Variables of Goal i
- g = Number of Goals
- k = Individual Player in the Game with DMU Set n
- n = Number of Trading Partners
- n_s = Number of Super Vendors from Multi-Objective Programming Model
- s = Number of Trading Partners in S_c
- w_i = Sub-Optimal Consensual Weight of Criteria i
- w_i^+, w_i^- = Weights of Criteria i to achieve Goal
- w_j^u = Net Worth Order Quantity from Supplier j in USD
- x_j = Decision Variable
- x_{io} = Input under Study
- y_{io} = Output under Study
- z_j = Decision Variable to Select Route which satisfies Binary Condition 0 or 1
- θ = Radial Input Efficiency
- $\boldsymbol{\lambda_j}$ = Column Vector of Reference Set
- ε = Non-Archimedean Element

6.2.3 Methodology to Retain Trading Partners in the 4PL Transaction Centre Sub-Optimally

The proposed model of transaction centre operates with efficient trading partners as per the 4PL principles (Kutlu, 2007). Pursuing with existing *like-minded* trading partners to reach the efficiency frontier through a consensual approach has been regarded apt (Cooper *et al.*, 2007). Although *best of breed* approach augurs well theoretically, synthesising the same practically involves time and trust factors due to the heterogeneous nature of chain partners (Visser, 2007; McCarter and Northcraft, 2007; Lin *et al.*, 2012). Hence, this kind of setup is not prevalent in SC environment and utilising the trading partners like a plug and play solution has been viewed as impractical. Thus, formulating an optimistic approach by giving a fair chance for every DMU to reach the efficiency frontier has been acceptable with a stipulated arm-length time. In addition, a new dimension of coordinating cross-segment DMUs (suppliers and LSPs) in the proposed transaction centre has been looked as an extension apart from the *best of breed* approach. Specifically, a sub-optimal solution to retain the trading partners has been suggested for a stipulated period. Here, the arm-length time period is characterised for short-term (Vachon *et al.*, 2013) and depends on the complexity of problem statement. This section deals with consensus formulation across the different category of trading partners for managing 4PL operations. Even though abundant literature is available on consensual approach (Chatterjee and Samuelson, 2002), a very little has been asserted from the 4PL application perspective. The cooperative models put forward the outcomes when trading partners come together with different combination (Vachon *et al.*, 2013). Here, interdependence among DMUs has been considered as differentiating parameter. Besides, cooperative practice signifies joint problem solving between trading partners and buying organisation (Visser, 2007). Therefore, escalating trading partners to become one of the *best of breed* DMUs has been considered appropriate through a consensual approach. By virtue of this approach, entire trading partners in the 4PL transaction centre can be retained in the form of sub-optimal solution.

In order to develop a consensual approach, appropriate weights among the trading partners have to be derived based on their individual performance for achieving equilibrium condition (Macbeth, 2002). For that reason, a heuristic based ordering mechanism has been recommended based on the output of the proposed 4PL transaction centre. In particular, OE attained from the optimal mergers has been considered in decreasing order. Moreover, ad hoc search methods based on the rules specific to a problem has been regarded as heuristics (Shapiro, 2002). Simplicity and effectiveness of heuristics has led to applied research for solving complex problems (Shapiro, 2002). This work differs from the existing cooperative approach reported by Cooper *et al.* (2007) with respect to permutation ordering mechanism of trading partners for calculating consensual weight w_i. The justification for adapting heuristic procedure is reported in the next section.

6.2.3.1 Justification for Heuristic Based Ordering Procedure

In Cooper *et al.'s* (2007) work, consensual w_i of the player k in a coalition has been estimated by calculating average value of the individual marginal contribution, known as *Shapley value*. Coalition S_c signifies integration of cross-segment trading partners in the transaction centre represented within { }. Moreover, this consensual approach has been discussed in section 4.2.3 and demonstrated in section 4.3.1 of chapter-4 in detail. Specifically, characteristic function ch( ) of individual S_c, 'ch(S_c)' has been reported for n trading partners. Further, *Shapley value* assumes equal probability in ordering of DMUs for all permutation occurrences (Cooper *et al.*, 2007) as follows:

$$\frac{1}{n!}\sum_{k\in S_c}(s-1)!(n-s)!\{ch(S_c)-ch(S_c-\{k\})\} \qquad \text{............................ (6.1)}$$

Here, s represents number of trading partners in the S_c and $ch(S_c)-ch(S_c-\{k\})$ calculates the marginal contribution of k. With increase in number of trading partners, the permutation of ordering combination increases drastically as depicted in equation 6.1. For instance, a trading partner pool of four suppliers has 24 permutation ordering options to arrive at final consensual w_i which is time consuming. In order to overcome this procedure, a heuristic based ordering procedure with respect to OE has been suggested in decreasing order based on the output of transaction centre. The rationale for this procedure dwells upon the notion that competition exists between trading partners in the distribution network (Cruijssen *et al.*, 2007; Antai and Olson, 2013). Therefore, the *Shapley value* approach has not been considered as the solution to arrive at consensual w_i in this thesis. Thus, the proposed heuristic approach has been considered to derive final w_i.

The heuristic ordering procedure has been explained by sub-dividing the clusters formed in chapter-4 into pool-1 and 2 based on the geographic spread of suppliers as shown in fig. 6.1.

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Figure 6. 1 Cluster-wise supplier DMU decomposition

For demonstration, cluster-1 with pool-1 suppliers (designated from A to I) has been considered by arranging them in decreasing order based on the attained OE scores as reported in table 6.1. In particular, the pool-1 region comprises of suppliers operating in and around Chennai belt along with corresponding LSPs.

Table 6. 1 Pool-1 suppliers arranged in decreasing order

Code	A	B	C	D	E	F	G	H	I
Supplier	S21	M28	G20	C01	M09	C14	C15	M05	M19

In principle, the recommended heuristic procedure emphasises on ordering mechanism based on the OE output attained from the 4PL transaction centre. This procedure enables the trading partner with maximum performance to attain the best possible weight in the pool of 4PL transaction centre. By virtue of this procedure, equilibrium condition has been obtained among trading partners in a consensual approach. Specifically, equilibrium condition deals with creating a common platform (Yang *et al.*, 2014) for deriving consensual weights of the suppliers. In this thesis, consensual w_i has been estimated among suppliers to distribute the total business spend for retaining unutilised LSPs sub-optimally. Here, specific to a trading partner (For example: suppliers), each supplier has been arranged in decreasing order based on OE score. Conversely, corresponding coalition trading partner's (For instance: LSP) influence has been considered to arrive at a normalised score matrix R_{ij} for ith player and jth criteria. However, the initial R_{ij} has been obtained from the projected output of new-cost efficiency model (see chapter-5) with corresponding LSPs as depicted in table 6.2.

Table 6. 2 Normalised score matrix of cluster-1 with pool-1 suppliers

Supplier		A	B	C	D	E	F	G	H	I	
Sl. No.	LSP										SUM
1	L01	0.6925	0.0236	0.0821	0.0374	0.0374	0.0220	0.0301	0.0374	0.0374	1
2	L02	0.7370	0.0169	0.0798	0.0318	0.0318	0.0151	0.0239	0.0318	0.0318	1

To put it succinctly, normalised revenue spend for the S_c has been utilised to derive consensual w_i. By virtue of all *Sc* combinations, score matrix has been prepared accordingly. Since, every supplier looks at maximising their outcome, ch( ) of individual S_c can be obtained using expression (4.6). In principle, the ch( ) of higher order coalition has been assumed to be less than or equal to lower order coalition (Cooper *et al.*, 2007). This situation can be mathematically represented for two trading partners P and Q as follows:

$$ch(\{P \cup Q\}) \leq ch(\{P\}) + ch(\{Q\}) \qquad \ldots\ldots\ldots\ldots\ldots\ldots (6.2)$$

Therefore, ch(S_c) for every coalition combination (A to I) has been computed to look at marginal contribution of supplier in the selected cluster. However, score for a S_c has been defined as the sum of individual supplier's score as measured by each criterion m (see Equation 4.7). Further, individual marginal contribution of suppliers with respect to coalition combination has been collated and analysed. For instance, marginal contribution of P in the coalition {P, Q} has been computed as shown in equation (6.3).

$$ch(\{P, Q\}) - ch(\{Q\}) \qquad \ldots\ldots\ldots\ldots\ldots\ldots (6.3)$$

From the different combinations secured, final consensual w_i of individual supplier has been estimated as depicted in table 6.3.

Table 6. 3 Suppliers contribution in a consensual approach

Sl. No.	Coalition	Individual Supplier Contribution	Weights
1	*c({ABCDEFGHI}) – c({ABCDEFGH})*	I	
2	*c({ABCDEFGH}) – c({ABCDEFG})*	H	
3	*c({ABCDEFG}) – c({ABCDEF})*	G	
4	*c({ABCDEF}) – c({ABCDE})*	F	
5	*c({ABCDE}) – c({ABCD})*	E	
6	*c({ABCD}) – c({ABC})*	D	
7	*c({ABC}) – c({AB})*	C	
8	*c({AB}) – c({A})*	B	
9	*c({A}) – c({ϕ})*	A	
Total Sum of Consensual Weights to Achieve Equilibrium			1.0000

In summary, these individual marginal contributions have been considered as consensual w_i to achieve equilibrium among suppliers in the pool of transaction centre. On the other hand, optimised total spend has been computed from the proposed merger cost combinations (see chapter-5). By multiplying the derived consensual w_i with the total merger cost, individual spend of suppliers on LSPs has been calculated for a coalition merger. Based on the number of LSPs in the selected cluster, individual spend of suppliers can be divided resulting in a sub-optimal solution. In this way, unutilised LSPs have been retained in the transaction centre pool sub-optimally. However, the proposed approach can be used only for a stipulated period. Attaining sub-optimal solution in the long-term has been regarded as working against 4PL principles (Chen and Su, 2009; Richey *et al.*, 2009). Hence, the intended approach has been viewed on an adjunct basis for treating trading partners equally. Thus, implementation of the intended procedure has opened a new area of enquiry to carry out research in 4PL parlance. Therefore, estimation of consensual weights for individual trading partner through OE based heuristic has made the procedure simpler and faster. Nonetheless, this procedure has been considered as pragmatic and one of the significant contributions to the existing knowledge.

6.2.4 Incorporating Policy Decisions and System Constraints in 4PL Transaction Centre Justification:

As the coordinator of 4PL transaction centre deals with cross-segment integration, trade-off between multi-criteria decisions has been viewed as critical (Cheng *et al.*, 2008). In order to address this issue, flexibility towards incorporating policy decisions and system constraints for selection of trading partners has been attempted. For instance, policy decisions deal with number of trading partners to employ and system constraints covenant with their capacity (Weber *et al.*, 2000) to coordinate transaction centre operations. This warrants for the application of goal programming techniques to make optimised decisions (Chen and Su, 2009). In particular, multiple goals with priority levels and weighted criteria has been formulated using multi-objective programming techniques (Sharma, 2006; Hajiagha *et al.*, 2012). Though the criteria defined have same priority in managing the 4PL transaction centre, different cardinal weights has been estimated to give importance among each other. These relative weights have been derived by calculating eigen vectors using Saaty's rating scale through pair-wise comparison of criteria (Saaty, 1980; Singh, 2013; Yadav and Sharma, 2015). Table 6.4 shows the adopted Saaty's rating scale.

Table 6. 4 Saaty rating scale

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Source: Saaty (1980)

For the study, castings supplier of cluster-1 (see chapter-5) has been considered. Further, three goals in the form of late delivery, rejection due to quality and average price of each component has been considered. The following criteria ratings from the Saaty's scale have been arrived in consultation with the buyers of tiller and tractor manufacturing company:

- Late Delivery (D) – [9]
- Rejection due to Quality Issues (R_q) – [5]
- Price of the Component (P) – [1]

Further, pair-wise comparison among the selected criteria has been carried out. The basic assumption with regard to carrying out pair-wise comparison signify that, if criteria-1 is considered more important than criteria-2 and rated as 9; then criteria-2 must be absolutely less important than criteria-1 and rated as 1/9. Therefore, the relative importance of one criterion over the other has been expressed in the matrix as follows:

$$\begin{array}{c|ccc} & D & R_q & P \\ \hline D & 1 & 5 & 9 \\ R_q & 1/5 & 1 & 5 \\ P & 1/9 & 1/5 & 1 \end{array}$$

Relative weights have been calculated by squaring the above pair-wise comparison matrix, calculating row-sum and normalising the column of row-sum. The same procedure has been repeated till relative weights become constant with respect to previous iterations (Singh, 2013). The final relative weights for the considered criteria (see Appendix D.1) has been reported as follows:

$D = 0.74$

$R_q = 0.21$

$P = 0.06$

Moving forward, multi-objective (goal) programming has been used for g goals with P_q priorities and different relative weights w_i^+/w_i^- for deviation variables d_i^+, d_i^-. The mathematical formulation for n variable multi-objective programming (Sharma, 2006) can be represented as follows:

$$\text{Min. } Z = \sum_{i=1}^{g} \sum_{q=1}^{Q} P_q \left(w_{i,q}^{+} d_i^{+} + w_{i,q}^{-} d_i^{-} \right)$$

subject to constraints

$$\sum_{j=1}^{n} A_{ij} x_j \,(\leq, =, \geq)\, B_i$$

$$\sum_{j=1}^{n} A_{ij} x_j + d_i^{-} - d_i^{+} = B_i$$

$$\text{and } x_j,\ d_i^+,\ d_i^- >= 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6.4)}$$

Let, Q represent number of priority levels, x_j denote decision variable, A_{ij} signify coefficient of decision variable j, $\boldsymbol{B_i}$ imply column vector of g goals. Based on the criteria and goals defined, an attempt towards integrating multi-objective programming and DEA has been carried out using Weber *et al.*'s (2000) model. Specifically, inputs comprising of objective function solutions along with surplus requirement of the castings supplier has been collated with common output through different policy decisions. Moreover, the suppliers selected from various policy decisions and system constraints has been identified as super vendors n_s. The mathematical formulation of DEA model to calculate efficiency θ from inputs $\boldsymbol{x_{ij}}$ has been represented in expression (6.5):

$$\text{Min. } \theta$$

$$\text{subject to constraints}$$

$$\theta x_{io} - \sum_{j=1}^{n_s} x_{ij} \lambda_j \geq 0$$

$$1 = \sum_{j=1}^{n_s} \lambda_j \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6.5)}$$

Here, n_s represent number of super vendors from the multi-objective programming model, x_{io} denote input under study, $\boldsymbol{\lambda_j}$ be column vector of reference set. From the secured results of DEA, optimal policy decision has been attained by achieving trade-off with system constraints. To address tie-situations, super efficiency DEA model can be applied to select the optimal policy decision. Al-Eraqi *et al.* (2010) further revealed that the strong correlation exists between efficient DMUs after applying super efficiency model. Here, efficiency scores have been obtained by eliminating the data of DMU under study from the solution set (Cooper *et al.*, 2007). The super efficiency DEA mathematical formulation has been characterised as follows:

$$\text{Min. } \theta - \varepsilon\, \mathbf{S}$$

$$\text{subject to constraints}$$

$$\theta x_{io} = \sum_{j=1,\neq 0}^{n} \lambda_j x_{ij} + s^-$$

$$y_{io} = \sum_{j=1,\neq 0}^{n} \lambda_j y_{ij} - s^+ \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6.6)}$$

Let, ε be non-Archimedean element, **S** represent slack/surplus variables, $\boldsymbol{x_{ij}},\boldsymbol{y_{ij}}$ denote inputs and outputs for ith category and jth DMU. x_{io}, y_{io} represent inputs-outputs under study. In this way, trade-off between policy decisions and system constraints can be obtained to manage the transaction centre optimally. Therefore, the above mentioned procedure assists coordinator to make effective decisions under MCDM environment. In 4PL parlance, an optimal combination of cross-segment DMUs for a particular activity can be merged in the transaction centre. Thus, achieving trade-off between policy decisions and system constraints for managing 4PL operations has been claimed as one of the extensions to the intended model.

6.2.5 Grouping of Trading Partners considering Delivery Time

Justification:

To coordinate the integration process in 4PL transaction centre, grouping of trading partners considering delivery time has been regarded as critical for logistics operations (Forslund *et al.*, 2009). As SC works in a dynamic environment (Tejpal *et al.*, 2013), apt mix of grouping cross-segment trading partners helps the 4PL operator to manage transaction centre effectively. In particular, generation of optimal route plan considering delivery time (Bennett and Klug, 2012) for the transaction centre ensures continuous supply to the buying organisation. Therefore, combination of mathematical programming techniques and heuristics has been adopted through unified optimisation methodology (Shapiro, 2002; Cebi and Byraktar, 2003). Besides, heuristics has led to applied mathematics research to solve complex mixed integer programming problems. Further, the heuristics methodology determines acceptable rather than optimal solution from a discrete set of events (Shapiro, 2002). Consequently, integer programming methods rigorously optimise the constraints which have been poorly handled by heuristics. Further, time and effort consumed to solve problems has been significantly reduced. In summary, unified optimisation methodology signifies SC problem as a mixed integer programming model (Cebi and Byraktar, 2003) which captures real life scenarios with extension.

Initially, requirement of the buying organisation from trading partners for a particular period has been captured with delivery time. In this thesis, 11 castings supplier from cluster-1 (see chapter-5) which makes weekly delivery to the company has been considered. Besides, the supplier's locations have been depicted as shown in fig. 6.2.

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Figure 6. 2 Supplier locations of cluster-1 DMUs

Capacity of individual suppliers has been attained from the projection details of quantity accepted output in the proposed transaction centre. Based on buying organisation's policy, distance matrix has been created from the company to individual supplier and from individual supplier to the other suppliers as shown in fig. 6.3.

	C01	C04	C05	C07	C09	C13	C14	C15	C19	C20	C26
CMY	340	367	358	364	360	368	328	343	354	358	371
C01		-	-	-	-	-	325	10	-	-	-
C04			13	3	8	1	209	-	8	13	4
C05				9	5	12	204	-	8	6	1
C07					5	4	211	-	10	14	4
C09						9	209	-	7	13	13
C13							210	-	9	13	4
C14								326	191	203	212
C15									-	-	-
C19										8	7
C20											6

'-': Greater than 400 km CMY: Company

Figure 6. 3 Distance matrix from the company to individual supplier and vice versa

Nevertheless, maximum distance a truck can travel between suppliers has been limited to 400 km per day. In the next stage, feasible routing solution has been identified based on the pre-defined heuristics rules considering delivery time. Here, a feasible routing solution ensures that every supplier will be visited exactly once like a travelling salesman problem in OR (Sharma, 2006). The following two heuristics rules have been applied for the study to select feasible routes starting with:

1. Least delivery time
2. Largest delivery time

In addition, the delivery cost of coordinating trading partners has been estimated from each feasible route. However, employing heuristics alone is not suggested due to lack of reliance on the attained solutions (Shapiro, 2002). Hence, the integer programming model has been applied as a part of unified optimisation methodology to yield optimal results. The mathematical formulation of integer programming model for M castings supplier indexed as i and N feasible routes indexed as j has been reported in expression (6.7).

$$\text{Min. } c_1z_1 + \ldots\ldots\ldots\ldots + c_Nz_N$$

$$\text{subject to constraints}$$

$$a_{11}z_1 + a_{12}z_2 + \ldots\ldots\ldots\ldots\ldots\ldots + a_{1N}z_N = 1$$

$$\ldots\ldots$$

$$\ldots\ldots$$

$$a_{M1}z_1 + a_{M2}z_2 + \ldots\ldots\ldots\ldots\ldots\ldots + a_{MN}z_N = 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6.7)$$

The objective function of the integer programming model aims at minimising cost c_{ij} in each route. However, M constraints ensure that each supplier will be selected once during optimisation. Let, decision variable z_j satisfy 0 or 1 binary condition and coefficient of decision variable a_{ij} denotes 1 if route j is selected or 0 otherwise. Based on the results of integer programming model, scientific analogy to group trading partners can be attained. This helps the transaction centre coordinator to manage supply considering delivery time as most of the SCs work in just-in-time concepts (Forslund *et al.*, 2009).

6.3 Industry Case Study

To develop the transaction centre model from application perspective, extensions with necessary and sufficient conditions has been validated with a specific case study. Results and discussions of the suggested extensions have been discussed in the next section.

6.3.1 Results and Discussions of Transaction Centre Extensions

6.3.1.1 Extension-1: Retaining Trading Partners through Sub-Optimal Solution

It has been suggested that only *best of breed* LSPs have to be retained in the proposed model of 4PL transaction centre. For instance, L05 LSP in cluster-2 and L07, L08 and L10 LSPs in cluster-3 has not been utilised (see chapter-5). Hence, a heuristic procedure to retain entire LSPs through a consensual approach has been proposed in a sub-optimal way. Specifically, pool-1 trading partners of cluster-1 has been considered for demonstration. Based on OE scores attained from the recommended transaction centre, suppliers have been arranged in decreasing order with corresponding LSPs. By virtue of this, the initial normalised score matrix R_{ij} has been reported in table 6.5 considering projected output of new cost efficiency model. In order to maximise the individual supplier outcome with coalition LSP, ch( ) for the attained R_{ij} has been highlighted as follows:

Table 6. 5 Normalised score matrix with the ch( )

		A	B	C	D	E	F	G	H	I	
Sl. No.	LSP										SUM
1	L01	0.6925	0.0236	0.0821	0.0374	0.0374	0.0220	0.0301	0.0374	0.0374	1
2	L02	0.7370	0.0169	0.0798	0.0318	0.0318	0.0151	0.0239	0.0318	0.0318	1

Similarly, coalition combinations for two supplier DMUs along with the ch(S_c) for all combinations has been reported in fig. 6.4.

In the same way, ch( ) for all the possible coalition combination has been estimated and the S_c score has been calculated by adding individual supplier score. By virtue of these S_c combinations, attempt to calculate individual contribution of the suppliers has been carried out. For instance, the individual contribution of supplier {A} and {B} in comparison with coalition {AB} has been demonstrated in fig. 6.5. From the below figure, it has been observed that coalition {AB} has cooperative solution compared to individual maximum gain of supplier {A} and {B} respectively.

	AB	AC	AD	AE	AF	AG	AH	AI
L01	0.7161	0.7746	0.7299	0.7299	0.7145	0.7226	0.7299	0.7299
L02	0.7539	0.8168	0.7688	0.7688	0.7522	0.7610	0.7688	0.7688

	BC	BD	BE	BF	BG	BH	BI
L01	0.1056	0.0610	0.0610	0.0455	0.0537	0.0610	0.0610
L02	0.0967	0.0487	0.0487	0.0320	0.0408	0.0487	0.0487

	CD	CE	CF	CG	CH	CI
L01	0.1195	0.1195	0.1040	0.1122	0.1195	0.1195
L02	0.1116	0.1116	0.0950	0.1038	0.1116	0.1116

	DE	DF	DG	DH	DI
L01	0.0749	0.0594	0.0676	0.0749	0.0749
L02	0.0636	0.0469	0.0557	0.0636	0.0636

	EF	EG	EH	EI
L01	0.0594	0.0676	0.0749	0.0749
L02	0.0469	0.0557	0.0636	0.0636

	FG	FH	FI
L01	0.0521	0.0594	0.0594
L02	0.0391	0.0469	0.0469

	GH	GI
L01	0.0676	0.0676
L02	0.0557	0.0557

	HI
L01	0.0749
L02	0.0636

Figure 6. 4 Coalition combinations with characteristic function

	A	B	C	D	E	F	G	H	I
L01	0.6925	0.0236	0.0821	0.0374	0.0374	0.0220	0.0301	0.0374	0.0374
L02	0.7370	0.0169	0.0798	0.0318	0.0318	0.0151	0.0239	0.0318	0.0318

	AB	ABC	ABCD	ABCDE	ABCDEF	ABCDEFG	ABCDEFGH	ABCDEFGHI
L01	0.7161	0.7981	0.8356	0.8730	0.8950	0.9251	0.9626	1.0000
L02	0.7539	0.8337	0.8655	0.8973	0.9125	0.9364	0.9682	1.0000

0.7606

Figure 6. 5 Coalition gain through consensual approach

Similarly, individual contribution of all the suppliers has been calculated in the transaction centre pool. Finally, the sub-optimal w_i has been reported in table 6.6. Moreover, equilibrium condition has been achieved among suppliers through a consensual approach. Thus, *Shapley value* is not considered to arrive at consensual w_i in this thesis.

Table 6. 6 Individual sub-optimal weights of suppliers

Sl. No.	DMU	Representative Weight
1	A (S21)	0.7370
2	B (M28)	0.0169
3	C (G20)	0.0798
4	D (C01)	0.0318
5	E (M09)	0.0318
6	F(C14)	0.0151
7	G(C15)	0.0239
8	H(M05)	0.0318
9	I(M19)	0.0318
Total Sum of Weights		**1**

Conversely, the total spend of USD 12,17,122 has been attained from the output of transaction centre by considering optimised cost of the final cross-segment merger. The contribution of each supplier with cluster LSPs has been derived by multiplying the consensual w_i with the total spend. Based on the number of LSPs, individual spend by the supplier can be calculated accordingly. Thus, this procedure ensures that entire LSPs have been retained in the pool of 4PL transaction centre on an adjunct basis. Also, inefficient LSPs can be encouraged to reach the frontier over a period of time for becoming a *best of breed* DMU. Therefore, the proposed heuristic ordering mechanism makes the procedure simple and effective compared to *Shapley value* approach for estimating consensual weights. In addition, the individual spend of cluster-1 suppliers has been revealed in figure 6.6 and 6.7 correspondingly.

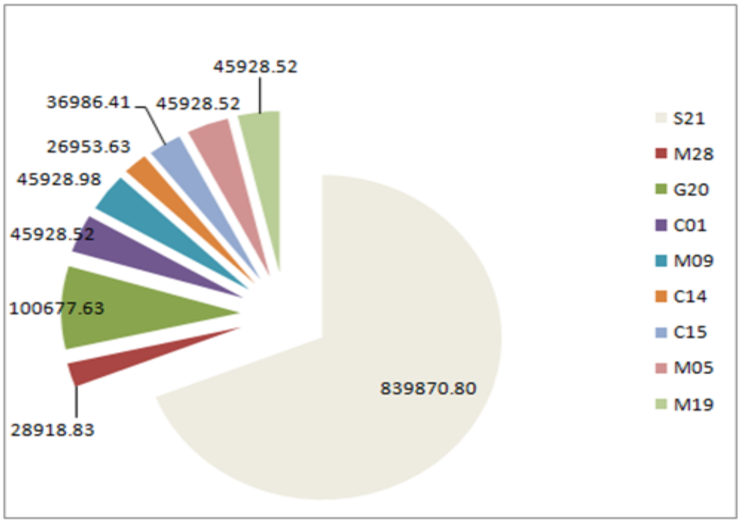

Figure 6. 6 Cluster-1 (pool-1) individual spend details

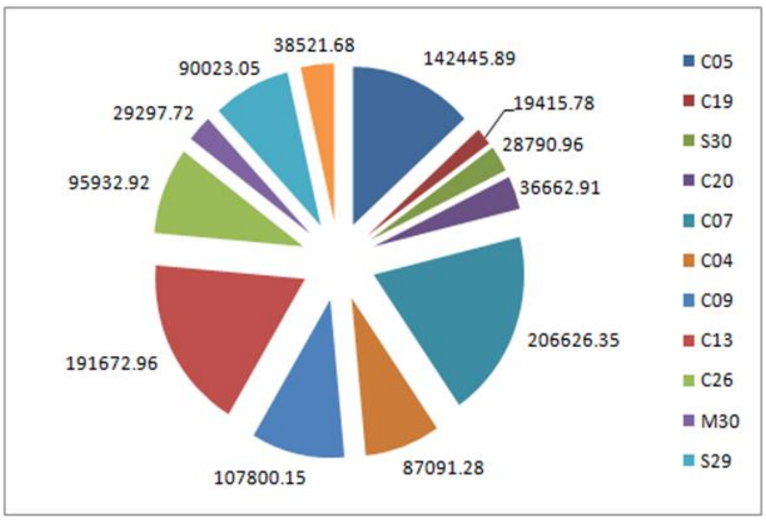

Figure 6. 7 Cluster-1 (pool-2) individual spend details

On similar grounds, the above mentioned procedure has been applied to cluster-2 and 3 trading partners respectively.

6.3.1.2 Extension-2: Trade-Off between Policy Decision and System Constraints

This research study involves 11 castings supplier from Chennai, Trichy and Coimbatore region (makers of transmission case, rotary side case, crankshaft pulley etc.). In addition, the financial value details of demand and supply has been collected as follows:

- Aggregate Demand Value in USD = 12,89,105
- Maximum Order Quantity Value in USD (Supply) = 12,91,516

Similarly, the following three goals has been viewed:

1. Late Delivery = 0%
2. Rejection due to Quality = 0%
3. Average Price of each Component = 8 USD

As the strength of SC relates to the weakest link in distribution network (Chopra and Meindl, 2007; Son and Orchard, 2013), equal priority of goals with different cardinal weights among criteria has been assumed. To capture this effect, mathematical formulation using multi-objective programming has been signified in expression (6.8) considering three goals:

$$\text{Min. } Z = \sum_{i=1}^{3} \left(w_1^+ d_1^+ + w_2^+ d_2^+ + w_3^+ d_3^+ \right)$$

subject to constraints

$$\sum_{j=1}^{n} x_j \geq D_a$$

$$x_j \leq w_j^u z_j \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6.8a)}$$

$$\sum_{j=1}^{n} z_j = V_r \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6.8b)}$$

$$\sum_{j=1}^{n} A_{ij} x_j + d_i^- - d_i^+ = B_i$$

Here, D_a denote average demand value in USD, w_j^u be net worth order quantity from supplier j in USD, $\boldsymbol{V_r}$ represent supplier selection vector, z_j imply decision variable with binary condition for selecting super vendors. However, expressions (6.8a) and (6.8b) characterises system and policy constraint respectively. In addition, the policy decision assumes minimum six suppliers for castings supply and system constraint ensures that production do not exceeds capacity. Moreover, these conditions can be modified by the coordinator to obtain optimal trade-off between supplier capacity and average demand. Figure 6.8 shows the optimal combination of suppliers to be selected known as super-vendors.

No. of Suppliers	C01	C04	C05	C07	C09	C13	C14	C15	C19	C20	C26
11	√	√	√	√	√	√	√	√	√	√	√
10	√	√	√	X	√	√	√	√	√	√	√
9	√	√	√	X	√	X	√	√	√	√	√
8	√	√	√	X	X	X	√	√	√	√	√
7	√	√	√	X	X	X	√	√	X	√	√
6	√	√	√	X	X	X	√	√	X	√	X

√: Suppliers Selected X: Suppliers Not Selected

Figure 6. 8 Optimal combination of super-vendors

In the next stage, results obtained from the multi-objective programming has been integrated into DEA model (see Expression 6.5) to arrive at optimal policy decision. Figure 6.9 portrays the results of policy decision.

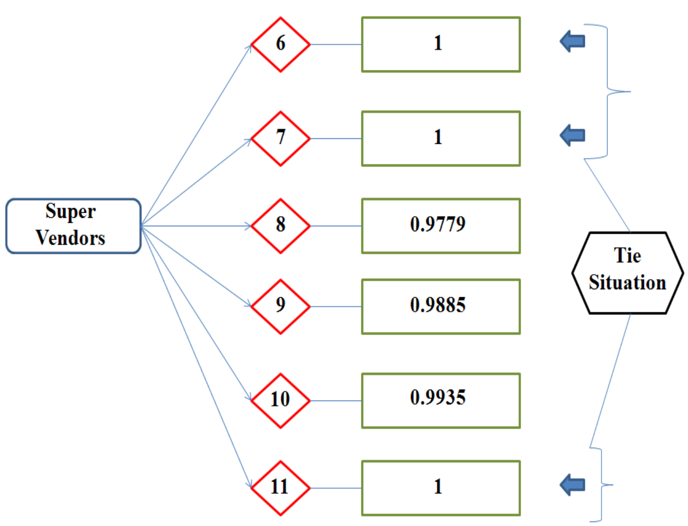

Figure 6. 9 DEA efficiency score from different policy decision

Tie-situation has been observed in selecting 6, 7 and 11 suppliers respectively. Therefore, super-efficiency DEA model has been applied to address tie-situation using expression (6.6). Results revealed maximum score for 11 supplier combination, thus, considered as an optimal policy decision as shown in fig. 6.10.

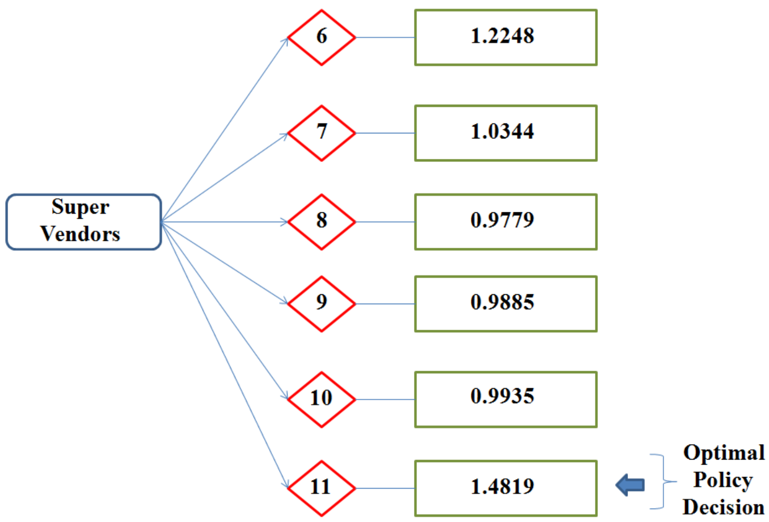

Figure 6. 10 Optimal policy decision from super efficiency DEA model

In this way, the coordinator of transaction centre can achieve trade-off between policy decisions and system constraints for managing 4PL operations effectively.

6.3.1.3 Extension-3: Optimal Route Plan Generation considering Delivery Time

Figure 6.11 portrays weekly requirement from suppliers by considering projected quantity accepted obtained from the proposed transaction centre.

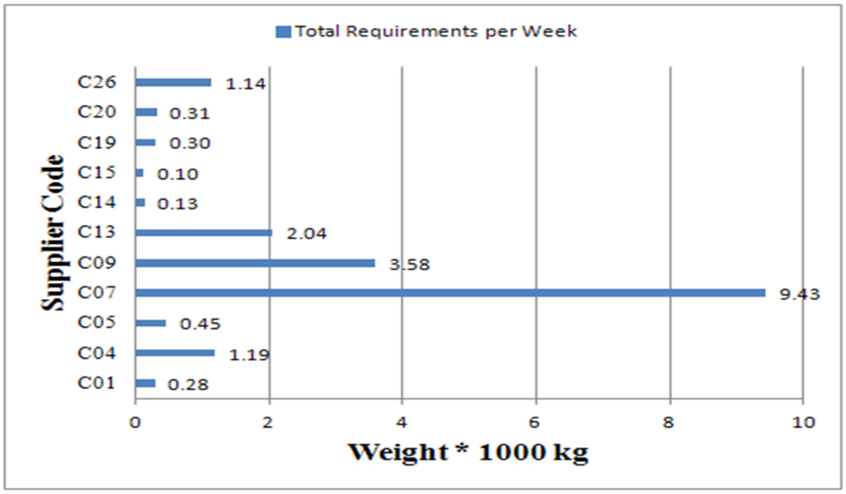

Figure 6. 11 Weekly requirement details to the company from suppliers

The average weekly demand has been estimated as 18,950 kg (18.95 tons). In addition, the average LSP cost has been calculated as 22.53 USD including overhead and variable cost for

1000 kg. Subsequently, attempt to identify feasible routes by means of heuristics with respect to delivery time has been carried out. Figure 6.12 shows an instance for selecting feasible routes under heuristics rule 1 and 2 respectively.

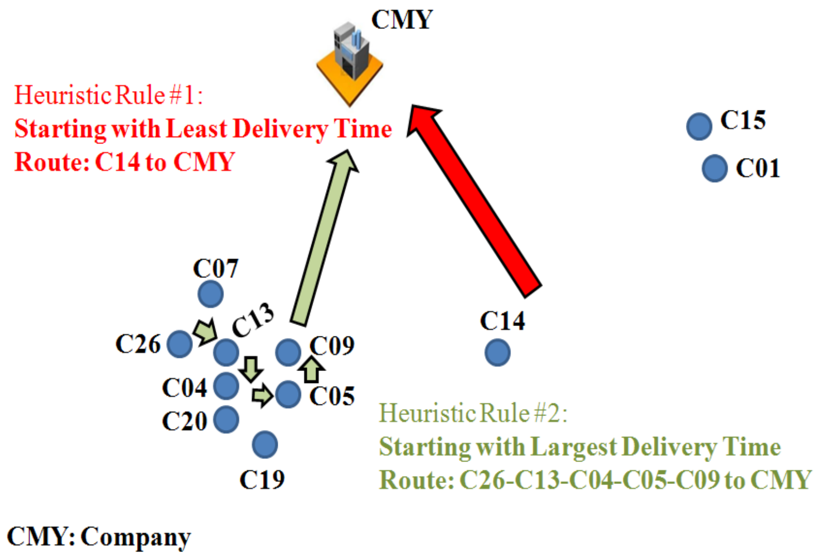

Figure 6. 12 Feasible route selection using heuristics

However, these rules have been applied till all the suppliers have been covered to get different combinations. By virtue of this, the delivery cost for individual route has been derived. Table 6.7 and 6.8 illustrates different combination of feasible routes along with delivery cost in USD obtained from heuristics rule 1 and 2 respectively.

Table 6. 7 Heuristic feasible routing solution-1

Sl. No.	Route	Suppliers Selected	Cost in USD
1.	1	0 - C14 - 0	2,929
2.	2	0 - C01 - C15 - 0	8,710
3.	3	0 - C19 - C05 - C09 - C13 - C26 - C04 - C20 - 0	2,02,970
4.	4	0 - C07 - 0	2,12,466
Total Cost of Feasible Route			4,27,075

Table 6. 8 Heuristic feasible routing solution-2

Sl. No.	Route	Suppliers Selected	Cost in USD
1.	5	0 - C26 - C13 - C05 - C09 - C04	1,89,151
2.	6	0 - C07 - C20 - C19 - 0	2,26,358
3.	1	0 - C14 - 0	2,929
4.	2	0 - C01 - C15 - 0	8,710
Total Cost of Feasible Route			4,27,148

By harmonising heuristic results with integer programming model, the optimised cost of USD 4,27,000 has been obtained. This accounts for less cost compared to either of the heuristic feasible routing solutions. Figure 6.13 shows grouping of suppliers to satisfy weekly demand considering delivery time and cost with different colour legends.

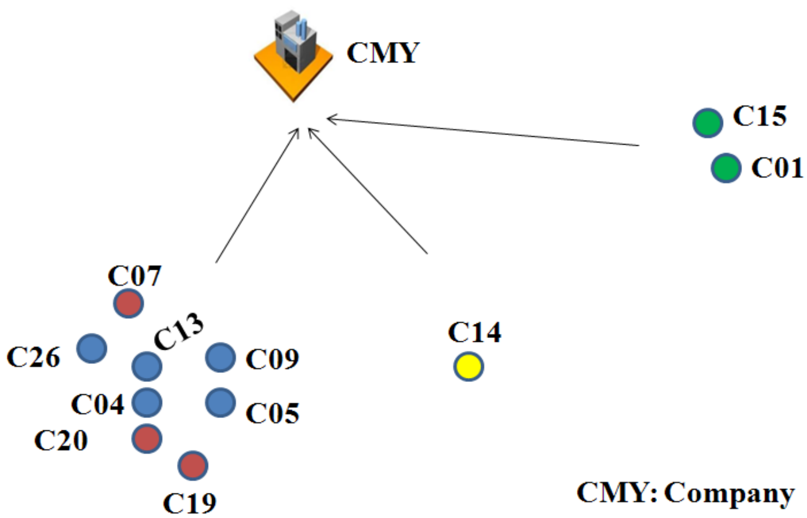

Figure 6. 13 Optimal grouping of suppliers considering delivery time

By virtue of the unified optimisation methodology, optimal route plan has been generated considering delivery time to ensure continuous supply by the 4PL transaction centre.

6.4 Concluding Remarks

In this chapter, distinguished features and characteristics has been embedded in the form of extensions to the 4PL transaction centre. Firstly, a heuristic based ordering mechanism has been recommended based on the output of 4PL transaction centre using OE scores. Present work differs from existing 4PL research by considering the entire trading partners to reach consensus through sub-optimal solutions. Moreover, the proposed heuristic ordering mechanism makes the procedure simpler and faster compared to the *Shapley value* approach for deriving consensual w_i. By virtue of this, total spend has been shared proportionately based on the attained consensual w_i. In principle, the suggested approach can be used only for a stipulated time period to ensure fair chance across the trading partners in order to become *best of breed* DMU. Thus, the recommended heuristic approach determines apt directions for trading partners to reach the efficiency frontier and satisfy 4PL principles in the long term. For illustration, it has been identified that L05 LSP in cluster-2 and L07, L08 and L10 LSPs in cluster-3 have not been utilised. Total spend of optimal merger costs in USD has been derived cluster and pool-wise correspondingly. By virtue of consensual weights, individual spend of each supplier along with cluster LSPs has been derived. Considering cluster-3 and pool-2 suppliers with total spend of USD 16,10,571, the proposed approach recommends 23% marginal contribution from C21 supplier that needs to be spent equally among five LSPs in the form of sub-optimal solution.

Moving forward, extension to the proposed model has been carried out to strike the balance between policy decisions and system constraints. In particular, flexibility towards achieving trade-off for selection of trading partners has been demonstrated using multi-objective programming and DEA. Incorporating trade-off approach reduces significant time on decision making for managing 4PL operations by the coordinator. The suggested methodology has been illustrated by considering 11 castings supplier of cluster-1 with demand value of USD 12,89,105 and capacity value of USD 12,91,516. From the final results secured, the policy decision revealed that 11 suppliers have to be integrated with model selected LSPs in order to satisfy the demand optimally. Nonetheless, a close resemblance of demand and capacity value validates the above claim.

Further, optimal route plan has been generated considering delivery time to ensure continuous supply by combining mathematical programming techniques and heuristics. For demonstration, optimal route has been generated considering weekly delivery requirements from 11 castings supplier to the company. By employing heuristic solutions with integer programming model, the optimised cost of USD 4,27,000 has been attained for coordinating activities of transaction centre. The integer programming model revealed grouping of suppliers with LSPs to satisfy the average demand considering delivery time. For example, the intended model suggests grouping C01 and C15 suppliers into one optimal route. By virtue of these extensions, application of the proposed transaction centre model for an industrial scenario has been demonstrated. In the next chapter, risk assessment and predictive model has been developed, implemented and validated for the 4PL transaction centre exclusively.

CHAPTER 7: PROACTIVE RISK MODELLING FOR THE DEVELOPED 4PL TRANSACTION CENTRE

7.1 Background and Preliminaries

Controlling SCM has become a huge challenge for the buying organisation due to ever-increasing complexity (Christopher, 2005) and this situation has made global organisations vulnerable to risks (Norrman and Jansson, 2004). Specifically, 4PL emergence is mainly due to the increased industry pressure for cost reduction and rise in service levels. Moreover, motives for utilising 4PL need well-defined objectives along with *like-minded* trading partners. For instance, the client organisation must be prepared for initial disruption risks during 4PL implementation and operational risks in the later stage (Kutlu, 2007). Hence, the risk parameters have to be viewed for ensuring un-interrupted supply apart from evaluating trading partners (Tummala and Schoenherr, 2011). Therefore, risk management has become one of the critical elements of SCM and contributes to the decision making process in cross-functional areas of business (Zsidisin and Ritchie 2009; Ganguly and Guin, 2013). This has led to significant interest in academia and industry for carrying out in-depth SC research (Christopher *et al.*, 2011; Wieland and Wallenburg, 2012; Ganguly and Guin, 2013). Thus, Supply Chain Risk (SCR) can be defined as "*the potential for an unwanted outcome resulting from an incident, event, or occurrence, as determined by its likelihood and the associated consequence*" (Tummala and Schoenherr, 2011; Badurdeen *et al.*, 2014).

SCR is dependent on chain partners which can be mitigated effectively by understanding the behaviour trends of network members (Faisal *et al.*, 2006). Also, impact of not considering risk management in the distribution network is critiqued with practical industry examples. Auto parts maker Collins & Aikman Corporation stopped supplying instrument panels and interior plastic parts to Ford Motor Company due to a misunderstanding over financial issues which led to production stoppage at Mexico plant (McCracken, 2006). Lunsford and Glader (2007) analysed root-cause for risk through Boeing Dreamliner-787 case study. As Boeing engineers concentrated on developing huge components like wings and fuselage of the aircraft, the company faced risk through shortage of nuts and bolts during public launch. Hence, detailed analysis of risks has to be made available to the SC coordinator in planning and management process. In addition, quantitative assessment is considered as a potential discipline for managing risk and creating policies to mitigate (Cox Jr., 2009). But, Wieland and Wallenburg (2013) reported lack of empirical research in SCR domain. In the next section, an overview of SCR is addressed for estimating risk in the distribution network.

7.1.1 Overview of SCR

Punniyamoorthy *et al.* (2013) reported the overall SCR model comprising of different dimensions as shown in fig. 7.1.

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Figure 7. 1 Dimensions of SCR

Source: Punniyamoorthy et al. (2013)

Considering a simple SC comprising of suppliers, manufacturers, LSPs and customers; risks from the constituent members of distribution network are highlighted. Information risk is viewed as another dimension in the SCR model as end to end visibility of the SC can be enhanced through data sharing (Christopher, 2005; Punniyamoorthy *et al.*, 2013). In addition, there is a scope for risks arising outside the SC environment. Hence, environmental risk is considered as the last dimension in the overall SCR model. After identifying different constructs of SCR, risk parameters can be identified with respect to a particular industry. In summary, the overall SCR model has six different dimensions to identify the potential sources of disruptions. Elahi (2013) re-iterated that buying organisations must be prepared for higher order uncertainties due to the complex business environments.

Moreover, the effective management of risks leads to the achievement of competitive advantage as shown in fig. 7.2.

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Figure 7. 2 Competitive advantage through effective SCR management

Source: Elahi (2013)

This warrants for a structured approach to manage SCR with the involvement of top management due to the dynamic nature of business environment. Besides, the uniform management of risk across the various categories of trading partners enhances SCR management capabilities. By virtue of the developed capabilities at a strategic level, buying organisation's can look for attaining competitive advantage. Golgeci and Ponomarov (2013) called for synthesising risk models considering other domains like operation's perspective instead of financial view point where abundant literature is already available.

Faisal *et al.* (2006) suggested identification of independent risk enablers based on their driving power in the network to understand their inter-relationships. Moreover, supply risks are dependent on the actions taken by network members in the distribution network (Cheng and Kam, 2008). The authors warranted for comprehensive evaluation of risk enablers and its impact for effectively managing the complexity of SC. Hence, dependencies between risk enablers has to be captured since it is ignored earlier (Pujawan and Geraldin, 2009). Besides, increased dependence on the chain partners makes buying organisation vulnerable to supply disruption risks. Christopher *et al.* (2011) analysed 15 cases across seven industries and found lack of systematic approach to assess SCR. The authors further classified SCR into supply, process, environment and demand risks as depicted in table 7.1.

Table 7. 1 SCR classifications

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Source: Christopher et al. (2011)

Kern *et al.* (2012) developed an empirical model for assimilating risk in the upstream SC by linking risk identification, assessment and mitigation along with continuous improvement as depicted in fig. 7.3. Based on operationalisation of SCR in the literature, the below conceptual model inter-links an effective way to enhance risk performance. This leverages a positive impact for implementing mitigation strategies by the decision makers. By virtue of performance outputs, improvements in risk identification, assessment or mitigation phase can be critically analysed individually or simultaneously reflecting continuous improvement philosophy (Ghadge *et al.*, 2013).

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Figure 7. 3 Conceptual model of supply risk management

Source: Kern et al. (2012)

To put it succinctly, a comprehensive coverage of risk enablers help the coordinator to assess SCR effectively for devising mitigation strategies. Empirical results showed that buying organisation's following these three systematic SCR management processes have performed well under risks (Cheng and Kam, 2008; Kern *et al.*, 2012; Ghadge *et al.*, 2013) by understanding SC complexities. The justification for synthesising risk-predictive model to the 4PL transaction centre is addressed in the next section.

7.1.2 Justification for Creating Proactive Risk-Predictive Model to 4PL Transaction Centre

The proposed 4PL transaction centre deals with multiple category of trading partners offering both opportunities and challenges. The economies of scale can be achieved by integrating trading partners, on the other hand, it increases the level of risk for managing transaction centre (Cheng and Kam, 2008). As the strength of transaction centre lies in selecting and coordinating cross-segment trading partners (Fulconis *et al.*, 2007; Visser, 2007), a prior information of risk helps the 4PL coordinator to minimise supply disruptions (Ghadge *et al.*, 2013). Moreover, robust analytical tools and new frameworks to capture dynamic risk factors in the distribution network are warranted (Badurdeen *et al.*, 2014). Hence, an integrated approach considering risk assessment and prediction model for the transaction centre fills the knowledge gap in 4PL risk management. In parallel, Prajogo and Sohal (2013) called for shift from reactive to proactive risk management in the current SC environment. Specifically, estimation of supply risk in a proactive manner for the recommended 4PL transaction centre is highlighted in this thesis. Estimating risk involves collecting information from different combinations of subjective and objective parameters of trading partners which lacks predictive analytics (Christopher *et al.*, 2011; Lockamy III, 2011). Wieland and Wallenburg (2012) linked SCR to the performance of network in terms of robustness and responsiveness (agility). The authors called for proactive strategies to deal with robustness and reactive strategies to covenant with responsiveness. In particular, proactive strategy is viewed as apt for the upstream SC and reactive strategy is considered appropriate for the downstream SC. As this research deals with upstream part of the SC, an attempt to develop a proactive risk-predictive model is carried out for the 4PL transaction centre. Further, Hittle and Leonard (2011) reported that the proactive risk model helps the coordinator of transaction centre to assimilate future uncertainties well in advance. Also, individual trading partners in the distribution network synthesise their own metrics and procedures for assessing and predicting risk (Badurdeen *et al.*, 2014). However, a little work is carried out in synchronising different metric scores for managing the transaction centre risk of 4PL. Hence, a proactive risk-predictive model for the transaction centre is warranted to ensure continuous supply. Besides, the recommended risk-predictive model is viewed from long-term operation's perspective by equipping capabilities and resources to the trading partners (Badurdeen *et al.*, 2014). Thus, selection of appropriate risk categories and its enablers are deemed critical to create a supply-risk management framework (Lockamy III, 2011, 2014). The author also warranted for applying Handfield and McCormack's (2007) risk assessment framework to evaluate supply risk which incorporates holistic view. In the subsequent section, rationale for adopting this risk assessment framework is elucidated.

7.1.3 Justification for McCormack's Risk Assessment Framework to Evaluate Supply Risk

Colicchia and Strozzi (2012) conducted a comprehensive review on SCR management based on the citation network analysis. This analysis captures the centrality of research papers by analysing citations in the highly cited papers. However, this analysis is different from the usual frequency based citation ranking mechanism. The authors found that the study conducted by Trkman and McCormack (2009) is entrusted as one of the top ten research article in SCR domain published in '*International Journal of Production Economics'*. Further, the said journal has the maximum number of citation network articles as reported in table 7.2.

Table 7. 2 Journals with maximum number of citation network articles

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Source: Colicchia and Strozzi (2012)

In particular, Trkman and McCormack's (2009) research article highlights the completeness of Handfield and McCormack's (2007) risk assessment framework to identify sources of supply disruptions holistically. Thus, McCormack's risk assessment framework is considered in this thesis. Also, the selected risk assessment framework is verified with various companies and validated with actual data for more than four years before publishing in the SC literature (Handfield and McCormack, 2007). Based on this framework, an exclusive 4PL risk predictive model is proposed, modelled and validated in this chapter.

In general, risk model developed for a particular region might not be appropriate for other geographical location. Despite this situation, there is an increasing trend of companies utilising 4PLs and a positive trend exists for synthesising exclusive 4PL risk models (Kutlu, 2007). Taking cue from this, a proactive risk-predictive model (Norrman and Jansson, 2004; Pujawan and Geraldin, 2009; Ghadge *et al.,* 2013) is developed in two phases. In the first phase, the risk assessment is carried out using Handfield and McCormack's (2007) framework considering six different enablers. In the second phase, risk predictive model is developed using Neural Networks (NN) methodology to manage SC disruptions (Kern *et al.*, 2012). Alternatively, Sreekumar and Mahapatra (2011) illustrated the application of NN methodology for prediction in uncertain situations to ensure transparency. In principle, the proposed model facilitates 4PL coordinators to identify intricacies of probable risks along with its impact in the supply network (Ghadge *et al.*, 2013). In the process of building NN risk model, datasets are normalised and subsequently optimised until actual and predictive Risk Probability Index (RPI) match through feed forward and back propagation techniques (Myatt, 2007). This index is calculated by multiplying scaling factors of potential risk events and probability of these enablers (Faisal *et al.*, 2006; Pujawan and Geraldin, 2009). Therefore, an attempt to proactively capture the heterogeneous risk behaviour of trading partners and creating a predictive model for the 4PL transaction centre is considered as one of the original contributions in this thesis. By virtue of this, the coordinator of transaction centre can identify risks proactively and devise mitigation strategies. The assumptions and parameters considered for the study are reported in the subsequent section.

7.1.4 Assumptions and Parameters

The assumptions include,

- Scaling techniques adopted in the risk assessment model has been mutually agreed between chain partners. Corresponding data to estimate marginal probability has been made available through RFI for the coordinator of transaction centre
- Learning rate to adjust weights in the NN has been assumed as 0.5 in order to train the risk-predictive model to estimate RPI
- Single hidden layer has been considered to generalise between input descriptors and output response (prediction). The number of neurons in the proposed NN risk model has been viewed as the size between input and output layer

The given parameters include,

- $Actual_i$ = Actual Response Value
- $Error_j$ = Calculated Error for the Node j
- $Error_{1i}$ = Error Resulting from Node i of Response Value
- $Error_{2i}$ = Error Resulting from the Hidden Layer Node i
- I_j = Input Value of Node j
- $Output_i$ = Computed Output for Node i
- $Output_{1i}$ = Predicted Response Value
- $Output_{2i}$ = Value of the Output from the Hidden Layer Node i
- X_j = Cumulative Input of Node j
- Xi = Input Predictors of the NN
- Y = Output Response of the NN

- l = Learning Rate which Ranges between 0 and 1
- w_{ij} = Weight on the Network Connection between Node i and j

Moving forward, first phase of the risk-predictive model for the transaction centre is carried out.

7.2 Risk Assessment Model

In this thesis, eleven casting suppliers from cluster-1 (see chapter-5) has been considered. After identifying risk enablers from the Handfield and McCormack's (2007) framework, assessment of SCR has been carried out in the first phase of model development. This model has six categories of risk enablers which can be characterised as Relationship, Performance, Human Resources, SC Disruption, Financial Health and Environmental Risk. Figure 7.4 represents the categories of risk enabler along with potential events which has the equal likely chance to occur in a SC.

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Figure 7. 4 Risk enablers in a supply chain

Source: Adapted from Handfield and McCormack (2007)

With regard to the problem statement and scope of the study, scaling factors have been defined using five point Likert's scale (Lockamy III, 2011) as shown in table 7.3 based on the considered tiller and tractor manufacuring company. Specifically, experience of buyers and suppliers has been taken into consideration before determining ratings for individual risk enablers as suggested by Giunipero and Eltantawy (2004). Besides, the description row in the table explains the analogy to select scaling factors from operations perspective.

Table 7. 3 Description of scaling techniques adopted

Sl. No.	Risk Category						
1.	Relationship	**Description**	**% of Production from Supplier Capacity**				
		Scaling Factor	1	2	3	4	5
		Criteria	> 90	> 65 - 90	> 15 - 65	> 5 -15	< 5
2.	Performance	**Description**	**% of Materials Accepted from the Deliveries**				
		Scaling Factor	1	2	3	4	5
		Criteria	> 99.5	> 99 ≤ 99.5	> 98 ≤ 99	> 97 ≤ 98	≤ 97
3.	Human Resources	**Description**	**Workforce Disruption**				
		Scaling Factor	1	2	3	4	5
		Criteria	Low	Low to Medium	Medium	Medium To High	High
4.	Supply Chain Disruption	**Description**	**Net Dependence from Kraljic's Matrix**				
		Scaling Factor	1	2	3	4	5
		Criteria	Acquisition	Profit	Security	Critical	To be Marked
5.	Financial Health	**Description**	**% Growth Rate in the Last Five Years**				
		Scaling Factor	1	2	3	4	5
		Criteria	> 30	> 20 - 30	> 10 - 20	> 5 - 10	< 5
6.	Environmental Risk	**Description**	**Supply Chain Disruption Potential (Natural, Political, Terrorist etc.)**				
		Scaling Factor	1	2	3	4	5
		Criteria	Low	Low to Medium	Medium	Medium To High	High

The analogy for determining ratings for various risk categories has been elucidated as follows:

1. **Relationship:** This refers to the percentage of production dedicated to the buying organisation based on supplier capacity. Here, higher the percentage of supplier capacity dedicated to the company infers positive relationship. With reference to various percentage breakups, scaling has been carried out accordingly. Moreover, this data has been obtained through RFIs submitted by the castings supplier (see Appendix-A.7)
2. **Performance:** This links to the ratio of quantity accepted to quantity scheduled. Based on the percentage of material accepted, scaling has been accorded. The quantity scheduled and accepted details has been collected from the master production schedule through IC-Soft ERP package

3. **Human Resources:** The analogy of this risk enabler deals with workforce disruptions. Based on the socio-economic condition of the supplier region, scaling has been carried out from Low to High as depicted in the above table. For instance, castings suppliers operating in Coimbatore region has been given lower scale (5) due to the high possibility of workforce disruption
4. **SC Disruption:** This risk category covenant with the proposed *Make-Shift* methodology results (see chapter-4). Here, suppliers in critical to acquisition cluster of the Kraljic's matrix has been given the rating of 1 to 4 in a hierarchical manner. Nonetheless, new suppliers in the transaction centre pool has been provided with the lower rating as 5
5. **Financial Health:** This has been captured based on the financial growth rate of suppliers in the last five years. Here, higher the percentage of growth rate infers better financial position of the company. With reference to various percentage breakups, scaling has been conducted respectively. Moreover, this data has been obtained through RFIs (see Appendix-A.7) submitted by the castings supplier
6. **Environmental Risk:** This risk refers to the unforeseen or uncontrollable situations in a particular region. Here, all the casting suppliers have been considered from the same region of operations. In this thesis, environmental risk has been ignored due to the common region of operations

On the other hand, the marginal probability technique has been implemented using past data and RFIs to estimate likelihood of risk occurrence (Ganguly and Guin, 2013). By combining individual scaling factors and probability, supplier's RPI has been estimated (Pujawan and Geraldin, 2009). Through RPI score, SCR has been determined considering total financial impact which quantifies the upstream supply risk (Zsidisin and Ritchie, 2009). In this thesis, optimal merger cost obtained from the proposed transaction centre (see chapter-5) has been considered as financial impact. The mathematical expression for SCR (Handfield and McCormack, 2007) has been shown using expression (7.1).

$$
\begin{aligned}
\text{SCR} &= (\text{Likelihood of the Event}) * (\text{Consequences}) \\
&= (\text{Probability of Occurrence}) * (\text{Total Financial Impact}) \\
&= (\text{RPI}) * (\text{Total Financial Impact}) \qquad \ldots\ldots\ldots\ldots\ldots\ldots (7.1)
\end{aligned}
$$

In principle, probability measures the likelihood of risk enabler occurrence and consequences quantify the financial impact. Besides, SCR score can be used for implementing mitigation strategies by proactively overcoming the uncertainties (Ganguly and Guin, 2013). Hence, suppliers with maximum SCR score has been indicated as high risk supplier which needs to be mitigated on a priority basis. In order to assess the risk with regard to high, moderate and low categories; prioritisation matrix has been employed as shown in fig. 7.5 to view all suppliers within a commodity group.

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Figure 7. 5 Risk prioritisation matrix

Source: Adapted from Handfield and McCormack (2008)

The matrix has been constructed by plotting impact versus probability of occurrence. In addition, the matrix acts like a visual sorting mechanism so that the suppliers with high risk can be prioritised for mitigation. In the second phase, a proactive risk predictive model has been developed using NN.

7.3 Proactive Risk-Predictive Model for the 4PL Transaction Centre

As the coordinator of transaction centre estimates future risk with a preventive approach, it has been termed as proactive risk-predictive model (Pujawan and Geraldin, 2009). To develop an effective risk prediction model for the 4PL transaction centre, input-output information pattern has to be analysed using data mining techniques (Sahay and Ranjan, 2008). In particular, NN model has been regarded as the most important prediction tool originated from artificial intelligence concepts (Heaton, 2005). Moreover, NN can be used for predicting business decisions (Venugopal and Baets, 1994; Aiken, 1999) using the training dataset of predictors (independent variables). In principle, this training dataset captures the relationship/behaviour between input predictors and output responses (Rajkumar and Bardina, 2003). Factors like ability to model linear/non-linear relationships, usage of categorical/continuous data and less sensitive to noise compared to statistical regression has been viewed as rationale for applying this methodology (Venugopal and Baets, 1994; Myatt, 2007). In this thesis, the NN risk-predictive model has been developed considering randomly selected five castings supplier as shown in fig. 7.6. Here, $\mathbf{X_i}$ signifies input predictors and **Y** represents predicted output response.

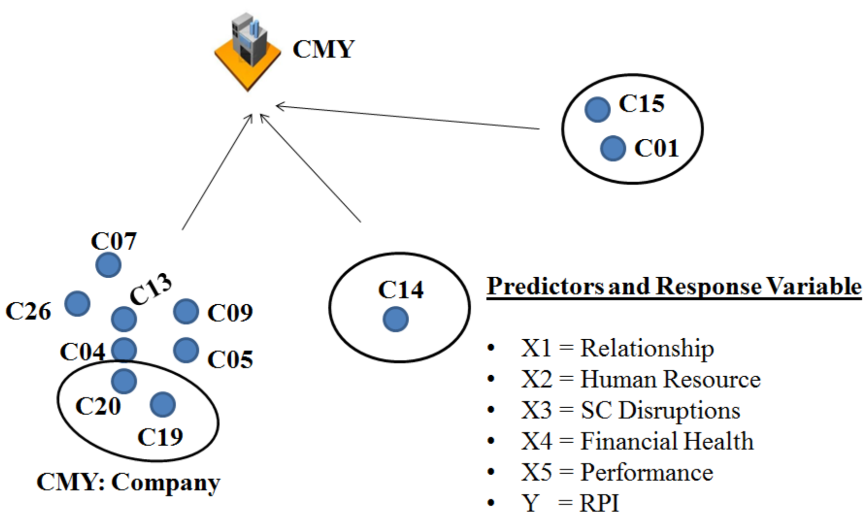

Figure 7. 6 Training set suppliers selected for RPI predictive modelling

7.3.1 Justification for Selecting the Training Dataset to NN

The training dataset to develop a proactive risk-predictive model for the 4PL transaction centre has been determined from different region of operations as depicted in fig. 7.6. Specifically, the castings supplier from various groups has been represented as training dataset to achieve completeness in the prediction process. By virtue of this, attempt to capture every supplier behaviour in different geographic area has been made holistically (Rajkumar and Bardina, 2003). This procedure ensures that the NN has been trained with all possible situations in the dataset in order to predict risk effectively (Belhadjali and Whaley, 2004; Chongwatpol, 2015). Also, a cross-validation technique has been used to determine appropriate number of predictors which maximises the predictive ability. 'Leave one-out' cross-validation approach has been executed for risk prediction calculations leaving one observation at a time.

Heaton (2005) reported lack of approaches to determine relationship and strength between the independent (inputs) and the dependent (outputs) parameters before constructing NN. Specifically, standardised approach to identify optimal number of independent variables (predictors) for the given dataset has been warranted (relationship). In addition, strength of the predictors with respect to the output response needs to be captured. In order to address these issues, multi-variate statistical analysis in the form of PLS regression has been applied to the predictors and output response variable (Ritchie and Brindley, 2007). PLS regression model derives optimal number of independent parameters for the proposed risk model by reducing the number of predictors into uncorrelated variables (Golgeci and Ponomarov, 2013). Therefore, identifying the optimal number of risk enablers (predictors) to estimate RPI (response variable) has been carried out using PLS regression model. The PLS model can be mathematically represented (Ritchie and Brindley, 2007) as follows:

$$RPI = f\,(\,Category_i\,) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(7.2)}$$

where 'i' represents individual category of risk assessment model

From the results of PLS model, risk-predictive model using NN methodology has been developed. Proactive estimation of risk for the transaction centre can be made in the future as and when the NN has been trained (Rajkumar and Bardina, 2003). In summary, risk enablers for the suggested proactive model has been identified using PLS regression and prediction mechanism has been attained through training NN.

Figure 7.7 illustrates the NN process adopted for proactive risk-predictive modelling through feed forward and back propagation technique. During feed forward process, the signals from input neurons pass through hidden layer and output neurons respectively. Based on the error between actual and predicted output, the NN has been made to learn through back propagation techniques.

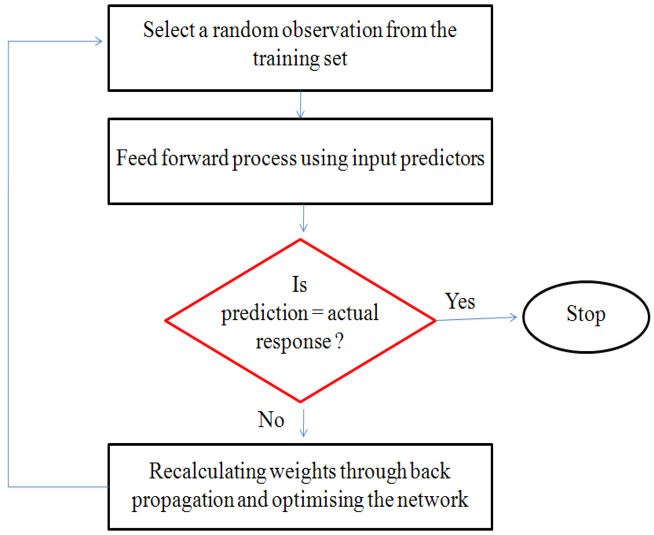

Figure 7. 7 NN model building process

The topology of a NN has been signified in fig. 7.8 which consists of input predictors, output responses and hidden layers. To substantiate further, Rajkumar and Bardina (2003) reported that the three layer NN can solve real-time complex problems along with sigmoid activation function. Also, higher to lower strategy of setting up the NN has been proved appropriate for randomly selected training datasets (Belhadjali and Whaley, 2004).

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Figure 7. 8 Topology of a NN

Source: Myatt (2007)

Initially, dataset has been divided into training and verification set in order to validate the trained NN (Myatt, 2007; Heaton, 2005). Input predictors and output response of the dataset have been normalised to avoid bias in the risk estimation process. Subsequently, the random weights between the nodes have been assigned in the range of '-1' to '+1' for training dataset. Individual node in the NN calculates single output value based on a set of input predictors and sigmoid activation function as shown in fig. 7.9.

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Figure 7. 9 Individual node output calculation

Source: Myatt (2007)

Hence, each node in the NN has been equipped with weights (w_{ij}) and set of individual input value (I_j). Cumulative input $\boldsymbol{X_j}$ for a node j has been calculated using w_{ij} and I_j as follows:

$$X_j = \sum_{j=1}^{n} I_j w_{ij} \qquad \text{……………….………………….(7.3)}$$

Similarly, individual output of a node $output_i$ has been computed by processing $\boldsymbol{X_j}$ through sigmoid activation function as portrayed in expression (7.4).

$$\frac{1}{1+e^{-X_j}} \qquad \text{……………………(7.4)}$$

After carrying out the feed forward process for all nodes, the output response $Output_{1i}$ has been compared with the actual response $Actual_i$. As the initial weights have been randomly assigned, the corresponding prediction has been considered void. Further, the learning process of a NN has been performed using back propagation technique to enhance the predictive accuracy. During the learning process, various inputs have been presented sequentially to the network by adjusting random weights to yield similar output (Venugopal and Baets, 1994). Here, weights have been adjusted during the learning process by estimating error from $Actual_i$ and $Output_{1i}$. Thus, the output layer response error $Error_{1i}$ has been measured using expression (7.5).

$$Error_{1i} = Output_{1i} * (1 - Output_{1i}) * (Actual_i - Output_{1i}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7.5)$$

Consequently, error has been back propagated to the hidden layer utilising expression (7.6). Here, $Error_{2i}$ represent error resulting from the hidden layer node; $Output_{2i}$ be value of the output from the hidden layer node and $Error_j$ denote calculated error for the node j.

$$Error_{2i} = Output_{2i} * (1 - Output_{2i}) * \sum_{j=1}^{n} Error_j \, w_{ij} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7.6)$$

Lastly, obtained error values have been utilised to adjust the weights (Adjusted w_{ij}) in the proposed risk model until predicted and actual response values match by employing expression (7.7). Here, l represent learning rate and the value has been assumed as 0.5 (Suarez *et al.*, 2006) to yield consistent prediction during a steady state scenario.

$$\text{Adjusted } w_{ij} = w_{ij} + (l * Error_j * Output_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7.7)$$

This technique has been repeated with different training datasets till the generalisation between input predictors and output response match. Presenting entire training dataset to the network once has been regarded as one cycle. Thus, the number of cycles has been decided considering the predictive ability between predicted and actual response value. Finally, the proposed proactive risk-predictive model has been evaluated by substituting the verification dataset to the optimised NN. After achieving significant predictive accuracy, the model can be used by the coordinator of transaction centre to estimate risk proactively with reference to existing trading partners. Therefore, the intended risk model helps 4PL service provider to reduce the impact on distribution network from supply disruption risks well in advance. In the next section, proactive risk-predictive model has been validated through a case study approach.

7.4 Industry Case Study

In the first phase, individual casting supplier's (Ci) SCR scores have been reported in fig. 7.10 using equation 7.1. For instance, C05 and C13 suppliers have high SCR score which has to be mitigated on a priority basis and critically reviewed before carrying out integration in the transaction centre.

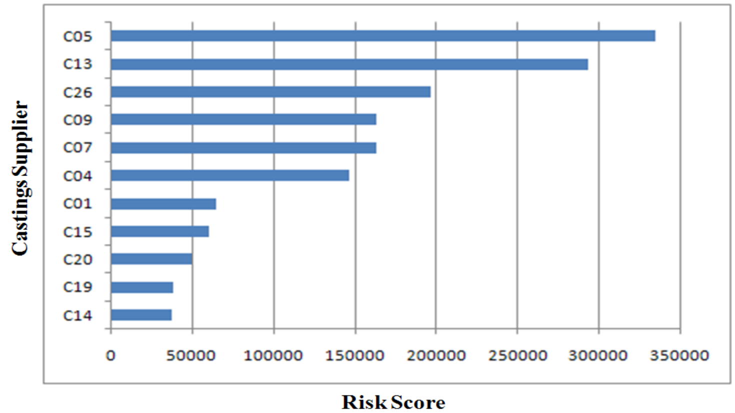

Figure 7. 10 Individual supplier SCR score

In this thesis, prioritisation matrix has been constructed considering financial impact in USD versus RPI using Kraljic's matrix. Supplier codes with red indicate susceptible to high risk. Similarly, supplier codes with yellow and green has been regarded as moderate and low risk suppliers respectively. Based on individual supplier colour code, prioritisation to carry out risk mitigation has been highlighted as depicted in fig. 7.11.

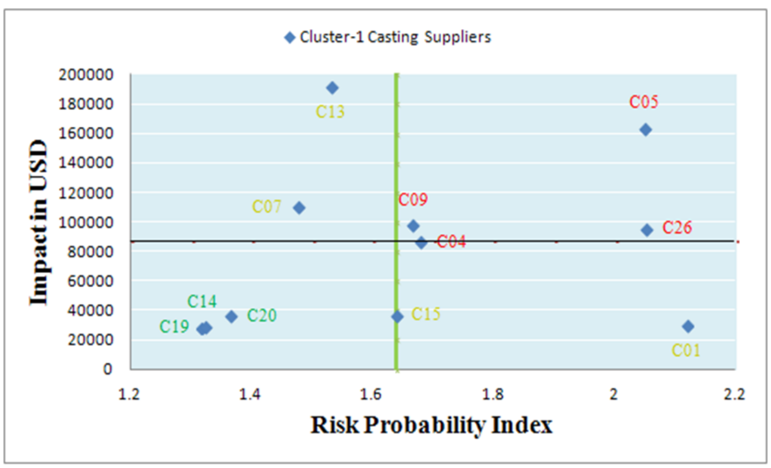

Figure 7. 11 Risk matrix of cluster-1 casting suppliers

In second phase, the identification of the optimal number of predictors for the proposed risk model has been formulated considering RPI as response variable and categories from Handfield and McCormack's (2007) risk assessment framework as predictors. Out of six categories, environmental indicator has been ignored. Thus, the risk categories considered for PLS regression analysis has been shown in fig. 7.12 with five predictors and one response variable.

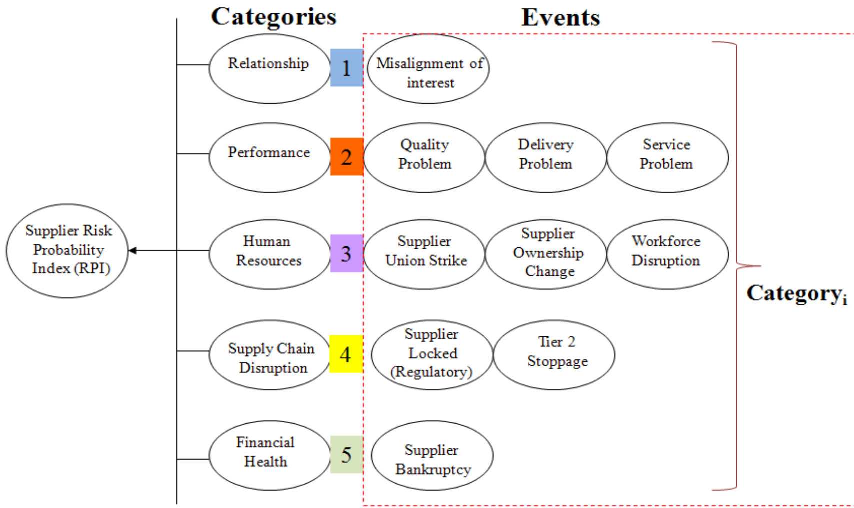

Figure 7. 12 Risk categories for PLS regression

After executing PLS regression, model selection plot signifies four predictors as optimal for the proposed risk model using fitted and cross-validation data. The vertical line validates the optimal number of predictors with highest co-efficient of determination (R^2) value as depicted in fig. 7.13. As p-value ≤ 0.05, the proposed model has been considered statistically significant.

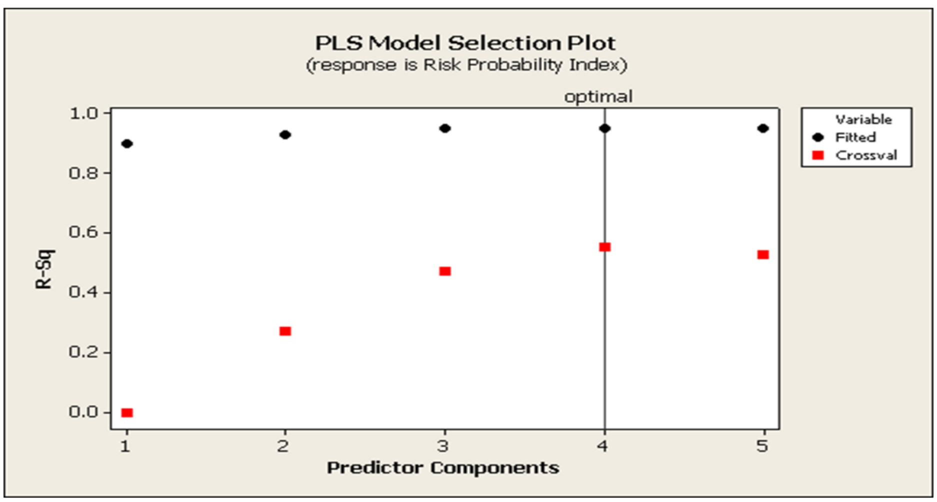

Figure 7. 13 PLS model selection plot

The loading plot exhibits relative influence of predictors on the response variable. Figure 7.14 denote performance predictor has the least impact on the response variable RPI. Thus, removal of the performance predictor variable has been suggested for the proposed risk model scientifically. Hence, the risk model with four predictors (Human Resources, Relationship, Financial Health and SC Disruption) yield adequate predictions with regard to the data considered for building NN.

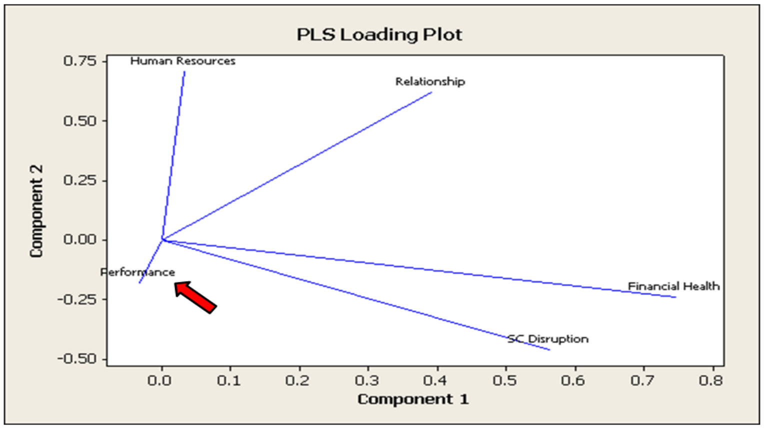

Figure 7. 14 Relative influence of predictors on RPI

The NN risk-predictive model has been developed considering normalised input-output data matrix of the training set suppliers as reported in table 7.4.

Table 7. 4 Description of normalised training dataset

Sl. No.	Training Set	Input Predictors				Output Response (RPI)
		X_1	X_2	X_3	X_4	Y
1.	C01	0.1290	0.2258	0.5161	0.1290	0.2732
2.	C14	0.2222	0.2222	0.4444	0.1111	0.1701
3.	C15	0.2353	0.4118	0.2353	0.1176	0.2113
4.	C19	0.0430	0.4839	0.4301	0.0430	0.1701
5.	C20	0.2326	0.5233	0.2326	0.0116	0.1753

Figure 7.15 portrays the initial NN predictive model with random weights for C20 supplier including actual RPI. The individual node output has been calculated using sigmoid activation function. After completion of feed forward process, the final output node determines predicted RPI. Once the error estimation has been calculated from actual and predicted RPI, the learning process has been performed using back propagation technique for the output and the hidden layer of NN. Subsequently, the error estimates have been used with l = 0.5 to adjust weights between the connecting nodes.

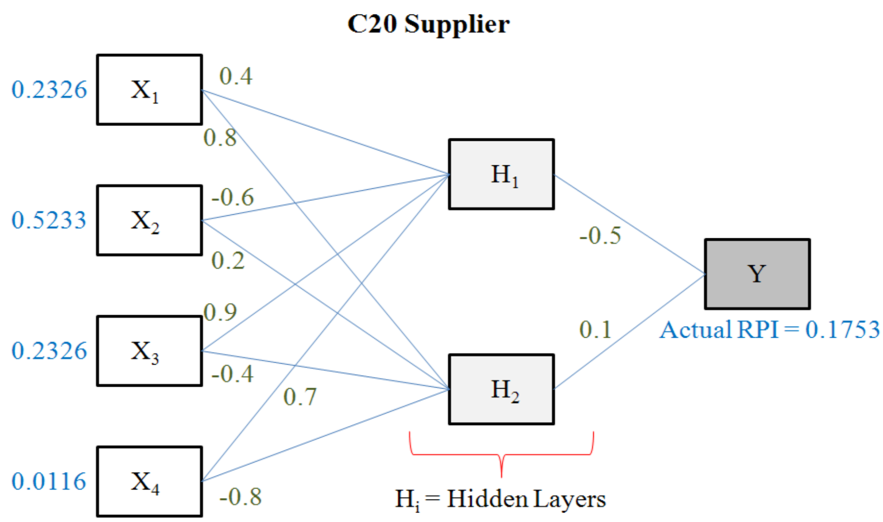

Figure 7. 15 Proposed NN predictive model

This procedure has been repeated for 50 cycles to generalise the relationship between input predictors and output response. However, predictive and actual RPI match with adequate predictive accuracy. The learning trend of predicted RPI against average actual RPI has been portrayed in fig. 7.16.

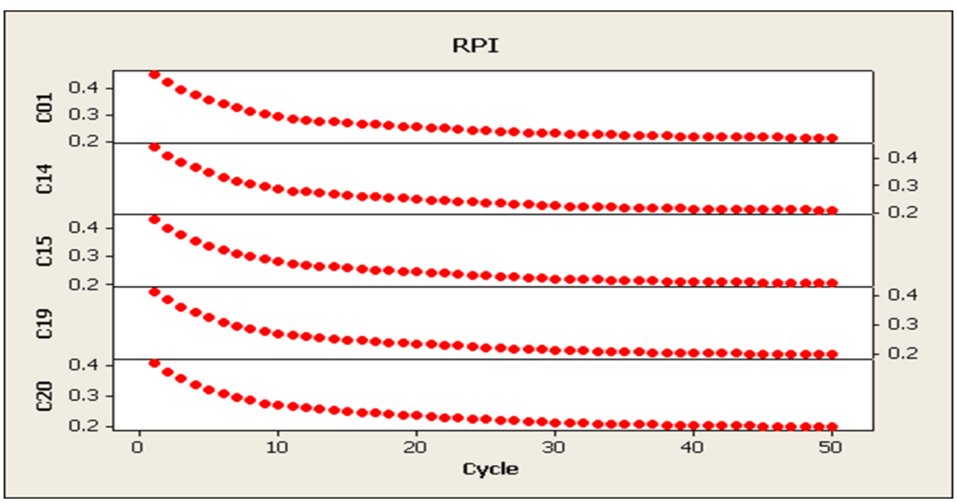

Figure 7. 16 Learning trend of the NN model

The above figure reveals that gap between predicted and actual RPI narrows down at 50^{th} cycle of learning through adjustment of weights. Finally, the NN optimisation has been stopped after 50 cycles as the network yields significant predictive accuracy as follows:

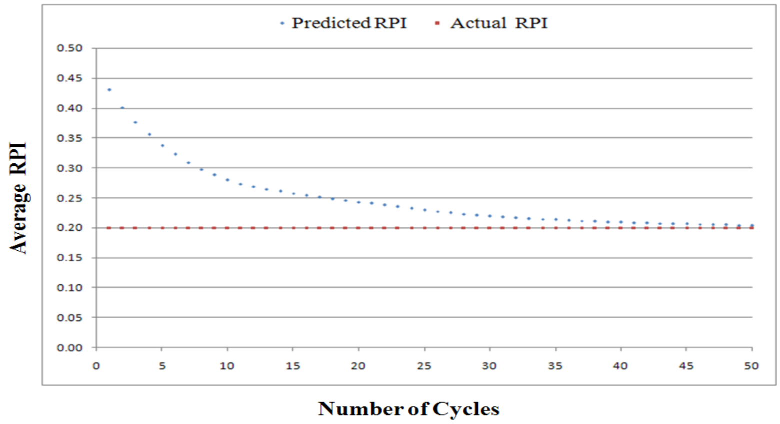

Figure 7. 17 NN optimisation of predicted RPI

The proactive NN predictive model along with weights has been reported in fig. 7.18.

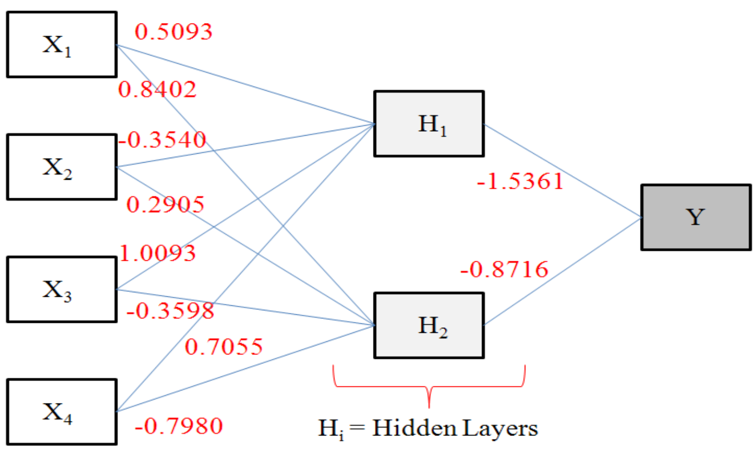

Figure 7. 18 Optimised NN predictive risk model

Further, the predictive model has been evaluated using verification dataset to ensure adequacy of the proposed risk model. However, predictive and actual RPI matched with minimum 85% accuracy from the trained NN model. Therefore, the final weights attained after the learning process can be used by the coordinator of 4PL transaction centre for predicting future risk.

7.5 Concluding Remarks and Suggestions

SCR is dependent on chain partners and can be mitigated proactively to reduce the impact of supply shortages. As the 4PL transaction centre deals with multiple categories of trading partners, it offers risk challenges to the coordinator. To precisely estimate 4PL risk, a new predictive model has been proposed in two phases for the transaction centre. The first phase deals with risk assessment of existing suppliers and the second phase covenant with synthesising a proactive risk-predictive model for the 4PL transaction centre. In summary, a risk-predictive model has been developed considering RPI as response variable and categories from Handfield and McCormack's (2007) risk assessment framework as predictors. Moreover, the proposed risk model synchronises different metric inputs and aggregates in the form of RPI through predictive analytics. Initially, training dataset has been presented to the NN in order to generalise the relationship between input predictors and output response. Once actual and predictive RPI match, the risk model has been evaluated using verification dataset to ascertain predictive accuracy. The key message from this chapter aims at furnishing the coordinator to foresee probable risks proactively before integrating cross-segment trading partners for consistent 4PL operations. Also, the trained model can be used as an auxiliary to the transaction centre for predicting risk in order to ensure continuous supply. As and when new trading partners have been added to the pool of transaction centre, the risk model can be trained to generalise the relationship. In principle, a proactive risk-predictive model to integrate different metric scores of trading partners into a common index for managing the 4PL transaction centre has been regarded as one of the contribution to the literature.

As an illustration, it has been found that four predictors yielded maximised predictive ability for the proposed risk model using PLS regression analysis. From the selected predictors, five castings suppliers (C01, C14, C15, C19, and C20) from cluster-1 has been further divided into separate training and verification datasets. In the next step, NN has been trained for 50 cycles with different dataset until RPI match between actual and predicted value. Finally, the determined weights can be used to proactively estimate future risk for the transaction centre. In the next chapter, conclusions and future work of the research study has been presented. Specifically, contribution to the body of knowledge has been highlighted from academic and industry perspective. Further, recommendations along with promising directions for the proposed model has been described.

CHAPTER 8: CONCLUSIONS AND FUTURE WORK

8.1 Conclusions

This chapter summarises the conclusions derived through the results of the research presented in this thesis. 4PL represents next stage of development in the logistics industry along with becoming an integral part of company's executive committee for the "*new generation*" SC (Win, 2008). The strength and value adding capacity of 4PL is linked to selecting and integrating trading partners in the transaction centre. Moreover, there is a transition in logistics industry to brokerage oriented culture signifying transaction centre approach. Hence, deep understanding of individual chain members across organisational boundaries has become mandatory to become a single point integrator. Therefore, the transaction centre of 4PL that can evaluate trading partners and comprehensively integrate the improved competencies of trading partners for sustaining the post-merger effects is warranted for effective SC operations. A critical review of literature did reveal that the development of transaction centre presents many challenges in the implementation role of 4PL service providers and monitoring cross-segment integration of trading partners. In particular, the challenges are identified in "*dependence on trading partners*", "*dynamic evaluation with output disposability function of lagged effects*", "*standardisation and control of integration process*", and "*minimising transaction cost*" characteristics. For the conceptual model of 4PL, EVA is identified as an appropriate measure of value creation to the client organisation but EVA lacks engineering meaning. To tackle these issues, an empirical way of synthesising transaction centre that can provide new capability operating standards is proposed using computationally efficient DEA. In summary, a 4PL transaction centre that can provide operating standards for merging cross-segment trading partners is developed in this thesis.

Selection of the *best of breed* trading partners is considered as a pre-requisite before conducting the cross-segment integration in 4PL transaction centre. In order to create this type of setup, an exclusive 4PL performance measurement framework is developed using interaction based parameters from trading partner's perspective and transaction based parameters from buying organisation's perspective. Besides, the suggested approach achieves completeness in the performance evaluation process. Chapter-4 deals with two parts in terms of identifying *like-*

minded trading partners prior to DEA evaluation and precisely capturing DEA performance under dynamic consideration respectively.

In the first part of chapter-4, the *Make-Shift* methodology is proposed as a pre-requisite adjustment procedure prior to the application of DEA approach in SC environment. Net dependence effect from trading partner's perspective is captured for clustering the network members into *like-minded* group using analytics. In view of the fact that DEA evaluates homogeneous trading partners, Kraljic's matrix with modifications is applied to cluster heterogeneous network members. The results demonstrate strong positive relationship across the *like-minded* trading partners which satisfy DEA principles for evaluation. In summary, the approach presented in this thesis can mitigate conservatism risks between the buying organisation and the trading partners for 4PL development.

In the second part of chapter-4, multi-stage DEA evaluation framework is developed considering time dynamics as an influential factor. Output of the framework equips coordinator of 4PL transaction centre to answer "*what-if*" scenarios for selecting appropriate network members to carry out cross-segment integration. In addition, the framework carries several implications by facilitating decision maker to identify critical input-output parameters for evaluation along with providing suggestive guidance for improvements. Besides, the dynamic evaluation with extensions to static model is carried out to study the interactions between trading partners by combining DEA and econometric models. The recommended framework minimises bias factor and rank reversals in the evaluation process, thus, reducing the gap between modelling and actual situations. Further, the projected evaluation scores provide guidelines to integrate trading partners in the transaction centre of 4PL. It is observed that static evaluation overestimates the efficiency score compared to dynamic consideration. In principle, this type of multi-stage framework makes the model realistic and helps the coordinator of transaction centre to synthesise performance evaluation models. Hence, combining the DEA and econometric models offer wide scope to carry out performance evaluation under MCDM environment. In summary, it is shown that embedding SC analytics with mathematical modelling approach enhances the coordinator capabilities to make decisions scientifically.

In chapter-5, Bogetoft and Wang's (2005) production economics integration model is extended from conventional similar-segment mergers to cross-segment mergers from operation's view point. The transaction centre is modelled to comprehensively integrate the improved competencies of third parties for 4PL operations in order to quantify the optimal merger gain. Specifically, the suggested model can provide new capability operating standards emphasising on the implementation role of 4PL service providers for cross-segment integration. To put it succinctly, an exclusive 4PL approach to evaluate and integrate trading partners in a dynamic transaction centre is developed. By virtue of the intended model, an objective approach for measuring value addition by the 4PL service provider is synthesised in the form of logistics asset. Sustainability of the proposed model is evaluated all the way through data variation and validated through non-parametric statistics. Verification of the model is performed through stability and sensitivity analysis under necessary and sufficient conditions to retain efficiency status of the merger. In summary, the proposed two-tier cross-segment integration framework can assist the 4PL coordinator to reduce transaction costs by aligning resources and developing synergies. By virtue of this approach, the relationship between evaluation and integration is verified with the pilot data and statistically validated.

Chapter-6 portrays strength and applicability of the suggested model through extensions to solve industry specific problems. Specifically, factors like sub-optimal 4PL solutions; balancing policy decisions and system constraints, and grouping trading partners with respect to delivery time are highlighted. Individual situations of extension are proposed, modelled and illustrated with an application case study. In order to retain all trading partners in the transaction centre, a sub-optimal solution is suggested using OE based heuristic ordering mechanism. In what follows, total spend is shared proportionately based on the marginal contribution of trading partners in the coalition. Therefore, a heuristic based ordering mechanism based on the output of 4PL transaction centre is recommended to escalate trading partners for becoming one of the *best of breed* network members with stipulated arm-length time. Further, an attempt to strike the balance between policy decisions and system constraints is executed for trading partner selection using multi-objective programming and DEA. In 4PL parlance, this approach facilitates coordinator to design optimal policies for managing the transaction centre considering multiple restrictions. In addition, incorporating trade-off approach reduces significant effort on decision making. Finally, extension to generate optimal route plan considering delivery time for a logistics operation is exhibited by combining heuristics and mathematical programming techniques.

As the proposed transaction centre of 4PL deals with multiple categories of trading partners, it offers both opportunities and challenges. Integrating trading partners influences economies of scale and increases risk for managing the 4PL transaction centre. To precisely estimate the future risk, a new proactive risk-predictive model is proposed for the 4PL transaction centre using PLS regression and NN approach in chapter-7. The proposed risk model synchronises different metric scores in the form of RPI through predictive analytics. Finally, the trained NN model can be used as an auxiliary to the transaction centre for predicting risk along with proactive critical review of integration relationships.

8.2 Findings and Original Contributions to the Body of Knowledge

The original contributions and findings from this thesis can be briefly summarised as follows:

- The *Make-Shift* methodology is proposed to estimate the net dependence effect from trading partner's perspective. In this method, clustering of heterogeneous trading partners into *like-minded* groups through modified Kraljic's matrix eliminates bias factor for further DEA evaluation. Further, the net dependence effect helps the coordinator of 4PL transaction centre to identify appropriate relationship that has to be maintained with trading partners before conducting the evaluation process. Conversely, an attempt to reduce the size of the SC problem in order to exploit DEA principles is put forward to induct right trading partners into the pool of transaction centre. The empirical application shows that positive correlation exists between *'best-peer'* and other trading partners in individual clusters. The recommended method has enabled a new line of thinking for carrying out SC research using DEA and can be generalised to other areas of DEA evaluation. *(validation in section 4.3.3)*
- In order to consider appropriate trading partners for 4PL operations, multi-stage performance evaluation framework is developed from buying organisation perspective.

This framework explores improvement stages from static to dynamic consideration. Specifically, the performance evaluation framework can deal with discretionary, non-discretionary and categorical situations along with dynamic consideration. The proposed dynamic evaluation differs from the existing research through output disposability relaxation of lag parameters signifying variable inter-temporal effects (positive, neutral or negative) between the chain partners. Besides, it is demonstrated that the dynamic evaluation system yields better performance results and provides pragmatic insights to improve technical and cost efficiencies. Thus, an integrated approach is formulated for the evaluation process wherein the resultant framework can be a generalisation to any industry. Also, the coordinator of 4PL transaction centre can look into the capabilities of all the trading partners before carrying out cross-segment integration *(validation in sections 4.3.3 and 5.3.4)*. In summary, an exclusive 4PL performance measurement framework to create a *best of breed* trading partner setup is a value addition to the logistics research. The novelty of the proposed 4PL performance measurement framework lies in its capability to integrate analytics with mathematical modelling resulting in a multi-stage framework

- An exclusive 4PL approach for the dynamic transaction centre is developed to comprehensively deal with a range of merger scenarios by arriving at operating standards. In particular, a novel two-tier cross-segment integration framework for the 4PL transaction centre is proposed prioritising performance orientation in the first tier and cost orientation in the second tier to quantify the merger gain. Therefore, a holistic approach is presented to assist the coordinator for assimilating operations process and implementation characteristics in the transaction centre. One can conclude that, a first attempt to merge cross-segment trading partners using DEA for the 4PL transaction centre is demonstrated. Further, the client and the 4PL organisation can optimally synchronise outside competencies with internal resources to enable transparency between the network members. In principle, the proposed model identifies *best of breed* trading partners auguring 4PL principles *(validation in sections 5.3.4 and 5.3.5)*. Thus, the integration framework developed in this thesis facilitates the coordinator of transaction centre to manage and control the activities of 4PL

- In some situations, it may be a buying organisation's desire to retain all the trading partners in the pool of transaction centre. To address such a scenario, an optimistic heuristic procedure to retain trading partners sub-optimally is proposed for a stipulated time period based on the output of 4PL transaction centre. The proposed OE based heuristic ordering mechanism makes the procedure simpler and faster compared to *Shapley value* approach by ensuring fair chance across the 4PL network members. Moreover, this approach has opened a new line of research in 4PL domain *(validation in section 6.3.1.1[Extension-1])*
- Adopting the suggested extensions enabled the 4PL transaction centre to address real-life industry problems and the coordinator can be equipped to manage 4PL operations effectively. The proposed extensions envisage to consider various aspects in multiple domains for making the intended transaction centre robust *(validation in sections 6.3.1.2 and 6.3.1.3 [Extension-2 and 3])*
- As the transaction centre comprises various categories of trading partners, risk is analysed proactively to minimise supply disruptions. A proactive risk-predictive model which can synchronise different metric scores of trading partners for estimating future risk is developed exclusively for the 4PL transaction centre. The recommended risk model consists of information which can help the coordinator of transaction centre to explore merger options proactively. Besides, the coordinator can foresee supply disruption risks in the future *(validation in section 7.4)*

8.3 Recommendations for Future Work

Recommendation _1: In the developed *Make-Shift* methodology, multi-criteria ranking approach to estimate net dependence effect is adopted. Moreover, this methodology facilitates the buying organisation and the 4PL service provider to identify appropriate relationship that needs to be maintained with individual trading partners. Some interesting directions include, but not limited to, application of advanced cluster analysis or classification techniques to categorise the trading partners into *like-minded* group.

Recommendation_2: In chapter-4, input-output parameters for multi-stage performance evaluation are specified from 4PL operations perspective. In addition, a fewer input-output parameters are considered for analysis and the multi-stage framework can provide evaluation results only with collated information signifying data dependency. Relaxing operations perspective assumptions on the input-output parameters can be a promising direction for future research. Nonetheless, robustness of the framework can be examined by ensuring data availability from multiple domains and assessing performance over time. Further, establishing mathematical relationships by incorporating stochastic modelling and simulation approaches can generalise the framework, thus, reducing the burden on coordinator to collect enormous data.

Recommendation_3: In the transaction centre model of 4PL, formulation developed to integrate cross-segment trading partners' dealt with only engineering viewpoint in the form of achieving technical and cost efficiencies. In addition, the proposed approach deals with two categories of trading partners (suppliers and LSPs) to perform integration in the transaction centre. Furthermore, homogeneous behaviour of the network members for carrying out cross-segment integration to make similar products with certain demand is considered. The proposed model can be extended to incorporate wide range of practical situations by considering human resource and cross-cultural effects due to the vast body of knowledge available in these domains. In course of enriching the model, incorporating different category of trading partners can lead to an important breakthrough research to sustain post-merger effects. Also, the model can add flexibility to look into the merger effect for multiple products with stochastic demand. Further, benchmarking the model with different type of industry settings is warranted to close the gaps between real life situations.

Recommendation_4: One extension for optimal route generation model created in chapter-6 is to consider more heuristic rules. Therefore, embedding heuristics solution comprising of more rules with applied mathematics is worth for further investigation to reduce logistics cost. In addition, incorporating spill-over shipping capabilities to achieve economies of scale can also be applied.

Recommendation_5: In the proactive risk-predictive model (chapter-7), the synchronisation of different metric scores to estimate the future risk is carried out. Thus, the extension to the risk model by incorporating contingency planning and risk mitigation strategies can be explored.

LIST OF PUBLICATIONS

1. Sharath Kumar, K.M. and Narahari, H.K. (2011) 'Estimating Net Dependence Risk from Suppliers' Perspective using Supply Chain Analytics for DEA Evaluation'. *International Review of Applied Engineering & Research*, 1(2), 155 – 174
(ISSN 2248-9967)

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(ISSN 2319-1171)

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(ISSN 2249-7196)

4. Sharath Kumar, K.M., Narahari, H.K. and Wright, N. (2014) 'Development of Proactive Risk-Predictive Model for 4PL Transaction Centre using PLS Regression and Neural Networks', *IUP Journal of Supply Chain Management*, 11(1), 36-51
(ISSN 0972-9267)

Paper Submitted:

1. Sharath Kumar, K.M., Narahari, H.K. and Wright, N. (2014) 'Overall Efficiency based Heuristic Approach to Retain Trading Partners in the 4PL Transaction Centre'. *International Journal of Production Research*

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APPENDIX

Appendix – A

A.1 Product Design Specifications

A.1.1 Power Tiller (Shakti 130 DI Power Tiller)

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Source: VTTL website

A.1.2 Tractor (Shakti MT180D Tractor with Rotary)

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Source: VTTL website

A.2 Vendor Assessment Questionnaire

DATE OF VISIT :

NAME OF THE VENDOR :

NAME OF THE M.D. :

PERSONS CONTACTED :

PRODUCT RANGE :

NO. OF EMPLOYEES : OFFICERS EMPLOYEES

ANNUAL TURNOVER :

CUSTOMERS OTHER THAN VTTL :

QUALITY SYSTEM IMPLEMENTATION ASSESSMENT RATING:

THE SYSTEM IMPLEMENTATION IS ASSESSED AGAINST EACH APPLICABLE QUESTION AND RATED AT A SCALE '0' TO '5' AS EXPLAINED BELOW:

NOT EXISTING	0
TRACES OF KNOWLEDGE	1
JUST STARTED	2
PREVAILING BUT REQUIRES LOT OF IMPROVEMENTS	3
SATISFACTORY BUT COULD BE STILL IMPROVED	4
EXCELLENT	5

QUALITY SYSTEM MANAGEMENT

	0	1	2	3	4	5
Whether Quality Manual is available? Does it meet ISO/ QS requirements						
Whether documented procedures are available for quality systems like document control, internal audits, procurement etc.						
Whether documents are controlled and distributed to the concerned and obsolete documents are destroyed						
Whether quality records maintained are adequate and easily retrievable. Whether retention period is documented and followed						

MANAGEMENT RESPONSIBILITIES

	0	1	2	3	4	5
Whether Quality policy and objectives are available, is it appropriate to the organisation and communicated to all. Does the Quality policy/ objective development evident in system						
Whether organization chart is drawn and responsibilities & authorities defined						
Whether Management Representatives (MR) is nominated with the responsibilities fixed and management reviews are taking place						

RESOURCE MANAGEMENT

	0	1	2	3	4	5
Whether resources/ facilities are adequate to the jobs under taken. Whether work environment is OK						
Whether human resource is adequate with respect to training, skill and experience						
Whether any jobs are sub-contracted, if so, whether controls are exercised. How are the requirements communicated?						

PRODUCT REALISATION

	0	1	2	3	4	5
Whether manufacturing processes are documented and controlled						
Whether control plan are available with critical characteristics identified						
*Is there planned programme for design and development? Whether design reviews are carried out systematically						
*Are all designs verified at each stage to ensure that output meets inputs? Whether design validation performed to ensure product performance						
*How are design changes implemented? Whether adequate control exercised on drawings, specifications						
Whether customer drawings are maintained properly and updates regularly						
How are the vendors approved? Whether the procedure is fair. Whether the approved vendor master is available						
Whether contract review is performed on VTTL P.O. and action on amendments to P.O. are taken						
Whether P.O. information is adequate when placed on sub-vendors						
How are purchased materials verified, accepted and stored?						
How is special process requirements communicated to sub-vendors?						
Whether work instructions and process sheets are adequate with defined product characteristics						
Whether production plan is available. Is plan vs. achievement is recorded and updated regularly						
Whether workshop is tidy; equipments and machinery are maintained properly						

Component batch wise tracebility is ensured. Whether in-process handling is fair. How are non-confirming products handled?						
Whether Quality control during manufacturing and those of outgoing components are fair. Whether recording of inspection data is adequate						
Whether special processes are identified, approved and audited periodically. Verify records						
Whether calibration system is operated effectively and records maintained						
Whether inspection and test certificates are sent to the customer along with the supplies						

Note: Question with * is applicable for own Design by Vendors

MEASUREMENT AND ANALYSIS

	0	1	2	3	4	5
Whether customer satisfaction is recorded and corrective actions are taken (VQR from customer)						
Whether vendor rating system is adopted for Sub-Vendors/ material suppliers						
Whether SPC/ SQC are applied and process capabilities of machines are carried out						
Whether non-confirming products are analysed and corrective actions are taken						
Whether internal auditors are trained and internal audits conducted						
Whether quality cost analysis is done and quality improvement plans prepared						
Whether corrective and preventive action system documented & implemented effectively						

ASSESSMENT OF QUALITY MANAGEMENT SYSTEM IMPLEMENTATION

Total Number of Applicable Questions : N

Total Number of Marks Scored : S

Degree of Fulfilment (Percentage) : S * 100/ N * 5 = ...%

Categorisation: A (Above 90%) B (75 – 89%) C (Below 75%)

A.3 Vendor Registration Form

VST TILLERS TRACTORS LIMITED
Post Box No. 4801, White Field Road, Mahadevapura Post, Bangalore – 560048

Supplier/ Company Name :
Address :

Telephone No. Telex No. Fax No. Email

TO BE COMPLETED BY THE SUPPLIER

1. Type of organisation : Proprietary / Private / Public Limited
2. Date of establishment
   (Also enclose Organisation Chart) :
3. Number of employees
   A) Management / Engineers :
   B) Supervisors :
   C) Skilled / Unskilled :
4. Items / Products manufactured :
5. List of Machinery : Use format given below

VST TILLERS TRACTORS LTD., SUPPLIERS INFORMATION FORMAT
PLANT, MACHINERY, MEASURING AND TEST EQUIPMENT DETAILS

SUPPLIER NAME :		ADDRESS :		TELEPHONE NO.:	DATE
PLANT, MACHINERY, TEST EQUIPMENT	YEAR OF MFG.	RANGE / SIZE	ACCESSORIES (IF ANY)	SPARE CAPACITY AVAILABLE IN TERMS OF HOURS	REMARKS

6. Source of raw material :

7. Quality System
   A) Whether ISO or QS certified :
   B) Details of incoming / outgoing inspection :
   C) Details of gauges used with calibration process :
   D) Type of training given to employees :

8. Name and Address of the Bankers :

9. Turnover for the last three years :

10. Balance sheet as on receipt date : Please attach Additional Sheet

11. List of major customers : Please attach Additional Sheet

12. Particulars of outside Financial Assistance : As below

		LIMITS		
NATURE	SOURCE	EXISTING	SOUGHT	
Cash Credit / Hypothecation Bills Discount Clean Over Draft Term Loan Guarantee's / Letter of Credit				

13. Are Sales Tax, P.F., Income Tax paid upto date : Yes / No
    A) Central Sales Tax number :
    B) Karnataka Sales Tax number :

14. Comments on availability of Raw Materials and Power :

NOTE: Please attach additional sheet wherever required.

STAMP OF THE COMPANY (SUPPLIERS SIGNATURE)

DATED

A.4 VTTL Purchase Order Format

VST Tillers Tractors Ltd.

Post Box No. 4801, White Field Road, Mahadevapura Post, Bangalore – 560048

Date: 25-10-XX

Purchase Order (PO)

Supplier Name	
Supplier Address	
PO Number	
PO Date	
Currency Type	

Part Name	Part Number	Quantity	Unit of Measurement Nos/Set	Price / Unit	Discount / Unit	Remarks	Sub-Total
						Total	A

Tax Details

Tax Type	Value	Sub-Total
Excise Duty (ED)	10%	
Education Cess on ED	2%	
SHE Cess on ED	1%	
CST	2%	
	Total	B
	Grand Total	A+B

Credit Period	
Terms and Condition	
Additional Comments/Remarks	
Delivery Schedule	

TIN Reg. No. - XXXX	Reviewed and Approved By	For VST Tillers Tractors Ltd.
Central Sales Tax No. - XXXX		
Address		

A.5 Vendor Quality Rating

VQR is calculated supplier-wise and product-wise based on the code assigned during GIR inspection. VQR is directly calculated and authorised by Quality department once in a quarter. It is printed and distributed to the vendors by SCP.

VQR calculation example is given below:

Part No.:

Vendor:

Period:

Sl. No.	GIR DATE	Part Name and Number	QTY. Received	QTY. Accepted	QTY. Rejected	Inspection Code	Remarks in GIR
1			200	200	-	1	
2			200	200	-	2	Minor Deviations
3			100	-	100	3	Rework Advised
4			100	90	10	3	Segregated
5			250	250	-	1	
6			150	150	-	1	

VQR (%) = [(200*100 + 200*75 + 100*0 + 100*0 + 250*100 + 150*100) / 1100]

= (75000/1000) = 75%

A.6 Total Vendor Ratings

TVR is also calculated along with VQR. However, the factors involved and method of calculation is given below:

Factor	**Quality (VQR)**	**Quantity**	**Delivery Date**
Weight	60%	20%	20%

WEIGHTAGE FOR QUANTITY		**WEIGHTAGE FOR DELIVERY**	
Quantity Factor	**Score**	**Delivery Date vs. Schedule Date**	**Score**
Supplied Qty. = + 5% / - 5% of Scheduled Qty.	20	-5 days to +2 days	20
Supplied Qty. = Lesser by 6 to 30% of Scheduled Qty.	10	Earlier than 5 days	10
Supplied Qty. = Lesser by more than 30% of Scheduled Qty.	0	Later than 2 days up to 7 days	10
Supplied Qty. = 106% or more of Scheduled Qty.	10	Later than 7 days	0

Example:

Date	Quantity		Delivery Date		Score	
	Schedule	Actual	Schedule	Actual	Quantity	Delivery
	125	100	20.4.XX	21.4.XX	100 * 10	100 * 20
	150	150	10.5.XX	15.5.XX	150 * 20	150 * 10
	150	150	25.5.XX	5.6.XX	150 * 20	150 * 0
	150	100	14.6.XX	5.6.XX	100 * 0	150 * 10
Total Score					7000	5000

Assuming VQR = 90%

TVR = (90*60)/100 + (7000/575) + (5000/575) = 54 + (12.2 * 0.2) + (8.7 * 0.2) = 58.18 %

A.7 Request For Information

VST TILLERS TRACTORS LTD.

Supply Management

Request For Information (RFI)

As We Develop Our Supply Strategies for Present and Future Requirements, the Following Information About Your Company will be Essential. Please Answer All Applicable Questions and Provide with Your Response Along with Recent Annual Report and Descriptive Literature on Your Products and Services.

1. General Information

Company Name:		
Company Address:		
Company Website:		
Key Contact:	Tel:	
	Fax:	
	E-Mail:	
Please Explain Your Company Structure Including Ownership, Divisions, Subsidiaries and the Nature of Joint Ventures and Strategic Alliances		
Please Explain Your Company History		
How Many People Does Your Company Employ?		
Total	Production	Staff
Research / Development	Management	Others

Who are Your Main Customers?			
Customer	Product(s)	Annual Volume	Annual Sales

What is the Total Annual Turnover/Revenue of Your Company?

Main Products Produced:

What is the Total Annual Capacity? (Pcs./Annum ; Tonnes/ Annum; Etc.)

What is the Actual Production Volume? (Pcs./Annum ; Tonnes/ Annum; Etc.)

What Volume of Production is for VST Tillers Tractors Ltd.?

What Percentage of Your Production is for VST Tillers Tractors Ltd.?

What is the Maximum Production You Would like to Allocate to VST Tillers Tractors Ltd.?

Whom do you Consider to be your Major Competitors?

Main Market Shares:				
Domestic	Europe	Asia	North America	Others

What was Your Company Growth Rate Over the Previous Five Years?	What is the Anticipated Growth Rate Over the Next Five Years?
What was your Company Total Investment Over the previous Five years?	What is the Anticipated Investment Over the Next Five Years?

2. **Quality**

Please List the National, International and Customer Accreditation Held by Your Company:			
Accreditation	Awarded By	For	Date (or Target Date)

What are the Quality Targets? (PPM)	Suppliers	In House Production	Delivered Quality
What is the Actual Quality Performance? (PPM)	Suppliers	In house Production	Delivered Quality

Does Your Company have a Quality Planning Procedure that Uses the Following Disciplines:			
Feasibility Studies	Failure Mode and Effects Analysis	Control Plan	Statistical Process Control
Gauge R&R	Poka-Yoke	Training Review	Total Preventive Maintenance Planning

What are the Minimum Acceptable Values Permitted by Your Company?	Cp / Cpk

Please List the Main Equipment that are Available under Following Criteria:		
Dimensional Assessment	Material Assessment Material Test Certificate	Leak Detection
Cleanliness Visual Check	Crack Detection	Plating / Paint Thickness
Torque Measurement Self Designed Equipment	Production Performance Tests	Component Validation Tests
Does Your Company have Cross Functional Quality Improvement Teams?		

Who are Your Major Suppliers	Company	Products

3. Cost

Please Describe Your Company's Business Practices and/or Annual Targets for the Following:
Open Book Costing
Single Tier Pricing for Production and After Market
Development and Delivery of Cost Reduction Projects With Customers
Development and Delivery of Cost Reduction Projects With Suppliers
Planned and Achieved Efficiency Savings
Customer Payment Terms and Condition

4. Logistics

Please Describe Your Company's Business Practices and/or Normal Activities in the Following Areas:		
Delivery to Customer (Methods Etc.)		
Delivery Frequencies and Improvement Activities		
Does Your Company have Direct Experience in the Following:		
Electronic Data Interchange	Just In Time	Capacity Planning

What is the Normal Lead Time for Production?
Does Your Company have the Ability to Manufacture at Short Notice (3 Days)

Note: Wherever Necessary Please Add Additional Sheets

A.8 Industry Support Letter from VTTL

V.S.T. TILLERS TRACTORS LIMITED.

Reg. Office & Factory : Post Box No.4801, Whitefield Road, Mahadevapura Post, Bangalore - 560 048.
Phone : 28510805/6/7, 28510275, 28510318 Fax : 91-80-28510221, e-mail : vstgen@vttlhq.com
Website : www.vsttillers.com

TÜV CERT ISO 9001 - 2000 Certificate:44100980026-E3 TÜV NORD

REF: VTTL:HRM:G-88A:2010 28 May 2010

Dr. M. D. Deshpande,
Professor and Head, Research,
M. S. Ramaiah School of Advanced Studies,
BANGALORE - 560 054

Dear Sir,

SUB: PERMISSION FOR INDUSTRY SUPPORT

Thank you very much for your letter dated 27-05-2010 regarding your Ph.D Scholar Mr. K.M. Sharath Kumar doing some research in our Company. We are happy to oblige to your request and permit Mr. Sharath Kumar to interact with my colleagues about one day in a week till the completion of his Doctoral programme which you are expecting may take three to four years. As I understand from your letter there is no financial implication from our side. He may utilise our data for carrying out his research only. We hope this interaction will be mutually beneficial.

Thanking you

Yours faithfully,
For VST TILLERS TRACTORS LIMITED,

(B.G. KODANDARAM)
ASST. GEN. MANAGER - HRM

28-5-2010

Manufacturers of :

SHAKTI® Power Tillers, Tractors & Diesel Engines in joint venture with
Mitsubishi Heavy Industries Ltd., & Mitsubishi Agricultural Machinery Co. Ltd. Japan.

VTTL/GA/102/10/07-2007

Appendix – B

B.1 Questionnaire for Ranking Dependent Parameters

VST Tillers Tractors Ltd.			
Post Box No. 4801, White Field Road, Mahadevapura Post, Bangalore – 560048			
Date:			
Questionnaire for Ranking the Dependent Parameters			
Sl. No.	Dependent Parameters	Ranking	Remarks
1	Communication		
2	Commitment		
3	Reputation		
4	Total Delivery Performance		
5	Total Quality Performance		
6	Trading Partner Capacity		
7	Years in Relationship		
8	Business Share in USD		
9	Innovation Capability		

Ranking Analogy:

- Rank 1 signifies higher the value for the dependent parameter
- Rank 9 signifies lower the value for the dependent parameter
- Here, ranking between 1 to 9 has been carried out relatively among the selected dependent parameters

B.2 Cluster Analysis of Castings, Sheet Metal, and Turned and Machined Suppliers

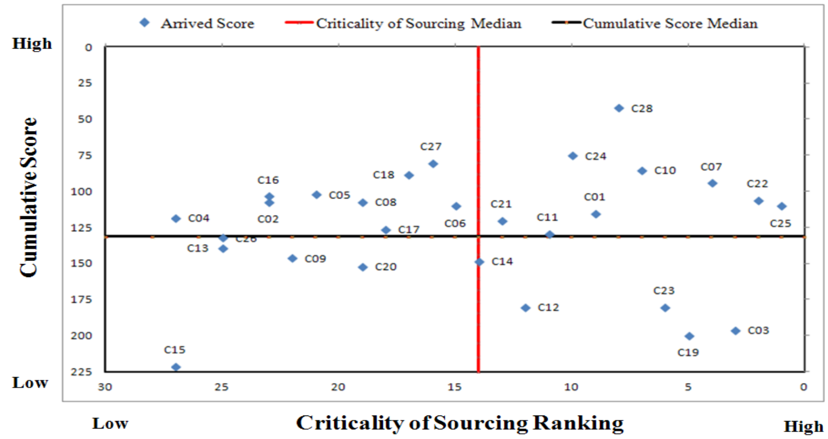

Figure B. 1 Cluster analysis of casting suppliers

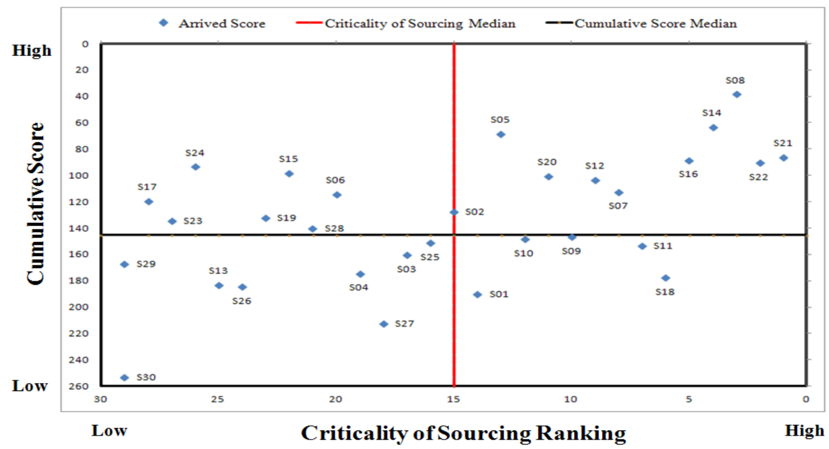

Figure B. 2 Cluster analysis of sheet metal suppliers

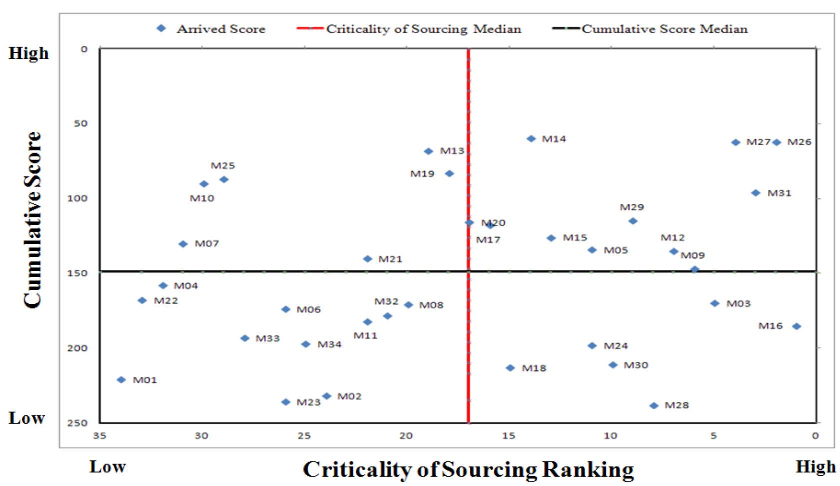

Figure B. 3 Cluster analysis of turned and machined suppliers

B.3 Working Principle of Wilcoxon-Mann-Whitney *T-statistics for S*electing the Hypothesis

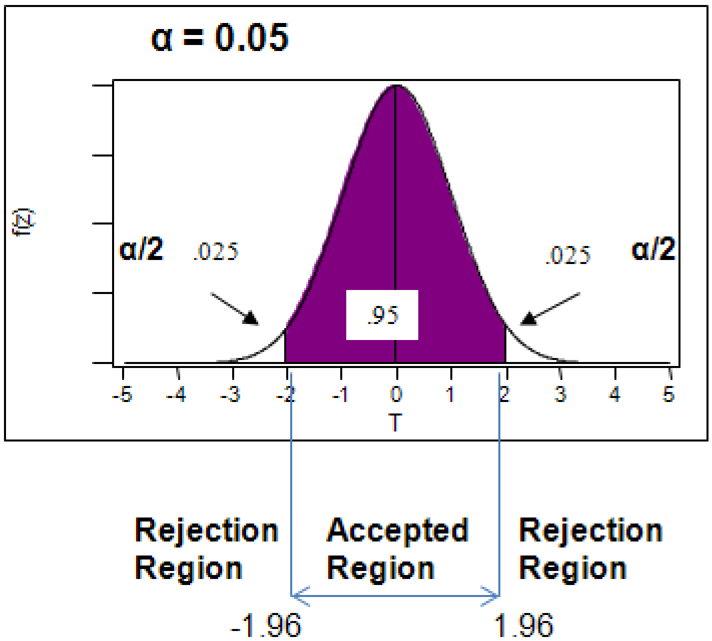

Figure B. 4 Standard normal distribution

$T_{calculated}$ is compared with $T_{critical}$ which refers to the table value of normal variable to arrive at inference. If $T_{calculated} \leq - T_{critical\ \alpha/2}$ or $T_{calculated} \geq T_{critical\ \alpha/2}$, $\mathbf{H_0}$ will be rejected. Here, $T_{critical\ \alpha/2}$ correspond to upper α/2 percentile of the standard normal distribution.

From the data of stage 4 and 5, $T_{calculated}$ = 0.48 under c-RTS

and

$T_{critical}$ = -1.96 (Table value for α/2, where α = 0.05)

Appendix – C

C.1 Wilcoxon Signed-Rank Test Illustration to Validate Difference in the Sensitivity Datasets

By virtue of median difference between two datasets (without and with data variation), $\mathbf{H_o}$ and $\mathbf{H_1}$ hypothesis is put forward accordingly. The calculated *T-statistic* is examined with critical *T-statistic* at α = 5%. Through left-tail test, the $\mathbf{H_o}$ will be rejected if the computed value is less than critical value of the Wilcoxon *T-statistic*. Conversely, the difference between population datasets is represented in expression (C.1) along with their signs. Further, ranking is carried out considering absolute difference. Nonetheless, dataset from the sample is removed whenever difference does not exist.

$$\text{Difference} = \text{Population 1} - \text{Population 2} \qquad \text{.................... (C.1)}$$

Consequently, sum of the positive [$\sum$ (+)] and the negative [$\sum$ (-)] rank is computed individually. In order to define Wilcoxon *T-statistic*, minimum of the two ranks is considered as shown in expression (C.2). Lastly, critical values is obtained from Wilcoxon *T-statistic* table at α = 5%.

$$T = Min\left[\sum(+), \sum(-)\right] \qquad \text{.................... (C.2)}$$

In this thesis, OE scores without and with data variation of sensitivity region is considered as Population 1 and 2 respectively. The following hypothesis is characterised:

$\mathbf{H_0}$:

The median difference between without and with data variation of sensitivity region = zero

$\mathbf{H_1}$:

The median difference between without and with data variation of sensitivity region ≠ zero

After carrying out the above mentioned procedure, it is observed that the $\mathbf{H_o}$ is rejected at α = 5%; since calculated test statistic is lesser than critical value. Therefore, $\mathbf{H_1}$ is accepted portraying differences in the sensitivity dataset.

Appendix – D

D.1 Eigen Vector Estimation through Pair-wise Comparison of Criteria Selected

Saaty's scale with following ratings for the supplier DMUs are considered:

- Late Delivery (D) – [9]
- Rejection due to Quality Issues (R_q) – [5]
- Price of the Component (P) – [1]

Using pair-wise comparison, the relative importance of one criterion over the other is expressed as follows:

$$\begin{bmatrix} & D & R_q & P \\ D & 1 & 5 & 9 \\ R_q & 1/5 & 1 & 5 \\ P & 1/9 & 1/5 & 1 \end{bmatrix}$$

Step 1: Squaring the matrix

$$\begin{bmatrix} 1 & 5 & 9 \\ 0.20 & 1 & 5 \\ 0.11 & 0.20 & 1 \end{bmatrix} * \begin{bmatrix} 1 & 5 & 9 \\ 0.20 & 1 & 5 \\ 0.11 & 0.20 & 1 \end{bmatrix} = \begin{bmatrix} 3 & 11.80 & 43 \\ 0.95 & 3 & 11.80 \\ 0.26 & 0.95 & 3 \end{bmatrix}$$

Step 2: Calculating row sum and normalising

$$\begin{bmatrix} 3 & 11.80 & 43 \\ 0.95 & 3 & 11.80 \\ 0.26 & 0.95 & 3 \end{bmatrix} = \begin{bmatrix} 57.80 \\ 15.76 \\ 4.22 \end{bmatrix} = \begin{bmatrix} 0.74 \\ 0.20 \\ 0.05 \end{bmatrix}$$

Step 3: Repeating this procedure till relative weight becomes constant with respect to previous iteration

After third and fourth iterations, the final criterion values along with their relative weights are reported as follows:

$$\begin{array}{ll} \text{Late Delivery} & \\ \text{Rejection} & \\ \text{Price} & \end{array} \begin{bmatrix} 0.74 \\ 0.21 \\ 0.06 \end{bmatrix}$$

Appendix – E

E.1 Medium Risk Research Ethics Approval

Medium to High Risk Research Ethics Approval
Read this first

Who should use this checklist?

You should only use this checklist if you are carrying out research or consultancy project through Coventry University: This includes:

- Members of academic, research or consultancy staff.
- Honorary and external members of staff.
- Research degree students (MA/MSc by Research, MPhil or PhD).
- Professional doctorate degree students (DHSC, EdD, EngD, DClinPsyc, DBA etc).
- Undergraduate students who have been directed to complete this checklist.
- Taught postgraduate students who have been directed to complete this checklist.

Who should not use this checklist?

You should not use this checklist if you are:

- An undergraduate student (Use the low risk ethics approval checklist first).
- A taught postgraduate student (Use the low risk ethics approval checklist first).
- A member of staff evaluating service level quality (Use the low risk ethic approval checklist first)
- Carrying out medical research or consultancy involving the NHS (Use the NHS online Integrated Research Application System (IRAS) form - https://www.myresearchproject.org.uk/Signin.aspx).

Can I begin work before the project is ethically approved?

No. Primary data collection can not begin until you have approval from one of the following:

- The Faculty Research Ethics Leader
- The Research Committee (RC)
- An External Research Ethics Committee (NHS Research Ethics Committee, Lead Partner University etc)

Alternatively, if you have established that your project does not require ethical approval using:

- Low Risk Ethical Approval Checklist

What will happen if I proceed without approval or falsely self-certify research ethics approval?

Collecting primary data in the absence of ethical approval or falsely self-certifying the level of risk associated with a project will constitute a **disciplinary offence**.

- For **Students** – this means disciplinary action resulting in immediate failure in any module or project associated with the research and potentially dismissal from the University.
- For **Staff** – This means disciplinary action, which may potentially lead to dismissal.

If you do not have ethical approval, the University's insurers will not cover you for legal action or claims for injury. In addition, you may be debarred from membership of some professional or statutory bodies and excluded from applying for some types of employment or research funding opportunities.

What happens if the project changes after approval?

If after receiving ethical approval your project changes such that the information provided in this checklist is no longer accurate, then the ethical approval is automatically suspended. You must re-apply for ethical approval immediately and stop research based on the suspended ethical approval.

What about multi-stage projects?

If you are working on a project which involves multi-stage research, such as a focus group that informs the design of a questionnaire, you need to describe the process and focus on what you know and the most risky elements. If the focus group radically changes the method you are using then you need to re-apply for the ethical approval.

Is there any help available to complete this checklist?

Guidance can be found in the ethics section of the Registry Research Unit Intranet. You will find documents dealing with specific issues in research ethics and examples of participant information leaflets and informed consent forms. Further advice is also available from:

- Director of Studies (Students)
- Faculty Research Ethics Leader (Academic Staff)
- Registry Research Unit (Students and Staff)

Which sections of the checklist should I complete?

If your project involves:	Please complete sections
Desk-research only, using only secondary or published sources.	**1, 2** and **16**
An application to an External Research Ethics Committee other than the NHS.	**1** to **4** and **16**
Collection and/or analysis of primary, unpublished data from, or about, identifiable, living humans (either in laboratory or in non-laboratory settings).	**1** to **15** and **16**
Collection and/or analysis of data about the behaviour of humans in situations where they might reasonably expect their behaviour not to be observed or recorded.	
Collection and/or analysis of primary, unpublished data from, or about, people who have recently died.	
Collection and/or analysis of primary, unpublished data from, or about, existing agencies or organisations.	
Investigation of wildlife in its natural habitat.	**1** to **5, 15** and **16**
Research with animals other than in their natural settings.	**Do not complete this checklist**. Contact the Registry Research Unit for advice

Research with human tissues or body fluids.	
Research involving access to NHS patients, staff, facilities or research which requires access to participants who are mentally incapacitated.	**Do not complete this checklist.** Make an application using the on-line NHS Integrated Research Application System (IRAS) form (https://www.myresearchproject.org.uk/Signin.aspx)

How much detail do I need to give in the checklist?

Please keep the details as brief as possible but you need to provide sufficient information for peer reviewers from the Research Ethics Panel to review the ethical aspects of your project.

Who are the Faculty Research Ethics Leaders?

Check the Registry Research Unit Intranet site for the most up to date list of Faculty Research Ethics Leaders.

How long will it take to carry out the review?

If your project requires **ethical peer review** you should submit this to your Faculty Ethics Administration team at **least three** months before the proposed start date of your project.

How do I submit this checklist?

The completed checklist and any attachments must be submitted to:

Faculty of Engineering & Computing: ethics.ec@coventry.ac.uk
Faculty of Business, Environment & Society: ethics.bes@coventry.ac.uk
Faculty of Health & Life Sciences: ethics.hls@coventry.ac.uk
School of Art & Design: ethics.ad@coventry.ac.uk
School of Lifelong Learning: ethics.soll@coventry.ac.uk

Medium to High Risk Research Ethics Approval Checklist

1 Project Information (Everyone)

Title of Project Modelling Fourth-Party Logistics Transaction Centre for Evaluation and Integration of Trading Partners using Data Envelopment Analysis
Name of Principal Investigator (PI) or Research or Professional Degree Student Mr. K.M. Sharath Kumar
Faculty, Department or Institute Asst. Professor, M.S.Ramaiah School of Advanced Studies
Names of Co-investigators (CIs) and their organisational affiliation Not Applicable
How many additional research staff will be employed on the project? Not Applicable Names and their organisational affiliation (if known) Not Applicable
Proposed project start date (At least three months in the future) 21 August 2010
Estimated project end date 31 August 2013
Who is funding the project? Self Funded Has funding been confirmed? Not Applicable
Code of ethical practice and conduct most relevant to your project: • British Computer Society • British Psychological Society • Engineering Council √ • Social Research Association • Socio-legal Studies Association • Other (Specify)

Students Only

Degree being studied (MSc/MA by Research, MPhil, PhD, EngD, etc) PhD
Name of your Director of Studies or Project Supervisor Dr. H.K. Narahari
Date of Enrolment: 21 August 2010

2. Does this project need ethical approval?

Questions	Yes	No
Does the project involve collecting primary data from, or about, living human beings?		√
Does the project involve analysing primary or unpublished data from, or about, living human beings?		√
Does the project involve collecting or analysing primary or unpublished data about people who have recently died other than data that are already in the public domain?		√
Does the project involve collecting or analysing primary or unpublished data about or from organisations or agencies of any kind other than data that are already in the public domain?	√	
Does the project involve research with non-human vertebrates in their natural settings or behavioural work involving invertebrate species not covered by the Animals Scientific Procedures Act (1986)?[1]		√
Does the project place the participants or the researchers in a dangerous environment, risk of physical harm, psychological or emotional distress?		√
Does the nature of the project place the participant or researchers in a situation where they are at risk of investigation by the police or security services?		√

If you answered **Yes** to **any** of these questions, proceed to **Section 3**.

If you answered **No** to **all** these questions:

- You **do not** need to submit your project for peer ethical review and ethical approval.
- You should sign the Declaration in **Section 16** and keep a copy for your own records.
- Research Students must ask their Director of Studies to countersign the declaration and they should send a copy for your file to the Registry Research Unit.

[1] The Animals Scientific Procedures Act (1986) was amended in 1993. As a result the common octopus (*Octopus vulgaris*), as an invertebrate species, is now covered by the act.

3 Does the project require Criminal Records Bureau checks?

Questions	Yes	No
Does the project involve direct contact by any member of the research team with children or young people under 18 years of age?		√
Does the project involve direct contact by any member of the research team with adults who have learning difficulties?		√
Does the project involve direct contact by any member of the research team with adults who are infirm or physically disabled?		√
Does the project involve direct contact by any member of the research team with adults who are resident in social care or medical establishments?		√
Does the project involve direct contact by any member of the research team with adults in the custody of the criminal justice system?		√
Has a Criminal Records Bureau (CRB) check been stipulated as a condition of access to any source of data required for the project?		√

If you answered **Yes** to **any** of these questions, please:

- Explain the nature of the contact required and the circumstances in which contact will be made during the project.

4 Is this project liable to scrutiny by external ethical review arrangements?

Questions	Yes	No
Has a favourable ethical opinion been given for this project by an external research ethics committee (e.g. social care, NHS or another University)?		√
Will this project be submitted for ethical approval to an external research ethics committee (e.g. social care, NHS or another University)?		√

If you answered **No** to **both** of these questions, please proceed to **Section 5**.

If you answered **Yes** to **either** of these questions:

- Sign the Declaration in **Section 16** and send a copy to the Registry Research Unit.
- Students must get their Director of Studies to countersign the checklist before submitting it.

5 More detail about the project

What are the aims and objectives of the project?

The aim of this work is to create a Fourth-Party Logistics (4PL) transaction centre model that can be used to comprehensively integrate the competencies of third parties for supply chain operations. The model will be generated in a format that is able to provide operating standards for integrating trading partners.

The following objectives must be met:

1. Review of literature pertaining to 3PL operations process and 4PL implementation characteristics and collect data
2. Categorisation of trading partners by estimating net dependence risk using analytical methods
3. Analysis of trading partners performance using DEA under static and dynamic considerations to leverage integration
4. Creation of 4PL transaction centre model that can be used to optimally integrate trading partners
5. Evaluation of transaction centre model through data variation and verifying the model using sensitivity analyses and cross validation

Briefly describe the principal methods, the sources of data or evidence to be used and the number and type of research participants who will be recruited to the project.

Data Envelopment Analysis methodology which can analyse multiple objective functions with reference to various independent variables simultaneously to arrive at single overall performance index will be used. Further, trading partners data will be collected from the company owned ERP software. In addition, no research participants will be recruited for the project.

What research instrument(s), validated scales or methods will be used to collect data?

Company owned ERP software (IC-Soft) will be used to collect data of trading partners (suppliers and logistics service providers).

If you are using an externally validated research instrument, technique or research method, please specify.

Not Applicable

If you are not using an externally validated scale or research method, please attach a copy of the research instrument you will use to collect data. For example, a measurement scale, questionnaire, interview schedule, observation protocol for ethnographic work or, in the case of unstructured data collection, a topic list.

Data will be collected with respect to following topics:

- Scheduled, received and accepted quantity of components (Gears, Sheet Metal, Machined and Turned and Castings)
- Number of main customers to the supplier
- Years in relationship with OEM
- Business share/Spend in USD
- Types of components supplying in numbers
- Criticality of sourcing

6 Confidentiality, security and retention of research data

Questions	Yes	No
Are there any reasons why you cannot guarantee the full security and confidentiality of any personal or confidential data collected for the project?		√
Is there a significant possibility that any of your participants, or people associated with them, could be directly or indirectly identified in the outputs from this project?		√
Is there a significant possibility that confidential information could be traced back to a specific organisation or agency as a result of the way you write up the results of the project?		√
Will any members of the project team retain any personal or confidential data at the end of the project, other than in fully anonymised form?		√
Will you or any member of the team intend to make use of any confidential information, knowledge, trade secrets obtained for any other purpose than this research project?		√

If you answered **No** to **all** of these questions:

- Explain how you will ensure the confidentiality and security of your research data, both during and after the project.

Data collected will be exclusively used for academic research purpose by the principal investigator only. After the research, data will be destroyed to ensure ethical protocol and will not be used for any other purpose.

If you answered **Yes** to **any** of these questions:

- Explain the reasons why it is essential to breach normal research protocol regarding confidentiality, security and retention of research data.

7 Informed consent

Questions	Yes	No
Will all participants be fully informed why the project is being conducted and what their participation will involve and will this information be given before the project begins?	√	
Will every participant be asked to give written consent to participating in the project before it begins?	√	
Will all participants be fully informed about what data will be collected and what will be done with these data during and after the project?	√	
Will explicit consent be sought for audio, video or photographic recording of participants?	√	
Will every participant understand what rights they have not to take part, and/or to withdraw themselves and their data from the project if they do take part?	√	
Will every participant understand that they do not need to give you reasons for deciding not to take part or to withdraw themselves and their data from the project and that there will be no repercussions as a result?	√	
If the project involves deceiving or covert observation of participants, will you debrief them at the earliest possible opportunity?	√	

If you answered **Yes** to **all** these questions:

- Explain briefly how you will implement the informed consent scheme described in your answers.
- Attach copies of your participant information leaflet, informed consent form and participant debriefing leaflet (if required) as evidence of your plans.

Industry support letter from the organisation will be sought before starting collection of data.

If you answered **No** to **any** of these questions:

- Explain why it is essential for the project to be conducted in a way that will not allow all participants the opportunity to exercise fully-informed consent.
- Explain how you propose to address the ethical issues arising from the absence of transparency.
- Attach copies of your participant information sheet and consent form as evidence of your plans.

8 Risk of harm

Questions	Yes	No
Is there any significant risk that your project may lead to physical harm to participants or researchers?		√
Is there any significant risk that your project may lead to psychological or emotional distress to participants or researchers?		√
Is there any significant risk that your project may place the participants or the researchers in potentially dangerous situations or environments?		√
Is there any significant risk that your project may result in harm to the reputation of participants, researchers, their employers, or other persons or organisations?		√

If you answered **Yes** to **any** of these questions:

- Explain the nature of the risks involved and why it is necessary for the participants or researchers to be exposed to such risks.
- Explain how you propose to assess, manage and mitigate any risks to participants or researchers.
- Explain the arrangements by which you will ensure that participants understand and consent to these risks.
- Explain the arrangements you will make to refer participants or researchers to sources of help if they are seriously distressed or harmed as a result of taking part in the project.
- Explain the arrangements for recording and reporting any adverse consequences of the research.

9 Risk of disclosure of harm or potential harm

Questions	Yes	No
Is there a significant risk that the project will lead participants to disclose evidence of previous criminal offences or their intention to commit criminal offences?		√
Is there a significant risk that the project will lead participants to disclose evidence that children or vulnerable adults have or are being harmed or are at risk of harm?		√
Is there a significant risk that the project will lead participants to disclose evidence of serious risk of other types of harm?		√

If you answered **Yes** to **any** of these questions:

- Explain why it is necessary to take the risks of potential or actual disclosure.
- Explain what actions you would take if such disclosures were to occur.
- Explain what advice you will take and from whom before taking these actions.
- Explain what information you will give participants about the possible consequences of disclosing information about criminal or serious risk of harm.

10 Payment of participants

Questions	Yes	No
Do you intend to offer participants cash payments or any other kind of inducements or compensation for taking part in your project?		√
Is there any significant possibility that such inducements will cause participants to consent to risks that they might not otherwise find acceptable?		√
Is there any significant possibility that the prospect of payment or other rewards will systematically skew the data provided by participants in any way?		√
Will you inform participants that accepting compensation or inducements does not negate their right to withdraw from the project?		√

If you answered **Yes** to **any** of these questions:

- Explain the nature of the inducements or the amount of the payments that will be offered.
- Explain the reasons why it is necessary to offer payments.
- Explain why you consider it is ethically and methodologically acceptable to offer payments.

11 Capacity to give informed consent

Questions	Yes	No
Do you propose to recruit any participants who are under 18 years of age?		√
Do you propose to recruit any participants who have learning difficulties?		√
Do you propose to recruit any participants with communication difficulties including difficulties arising from limited facility with the English language?		√
Do you propose to recruit any participants who are very elderly or infirm?		√
Do you propose to recruit any participants with mental health problems or other medical problems that may impair their cognitive abilities?		√
Do you propose to recruit any participants who may not be able to understand fully the nature of the research and the implications for them of participating in it?		√

If you answered **Yes** to **only the last two** questions, proceed to **Section 16** and then apply using the online NHS Research Ethics Committee approval form.

If you answered **Yes** to **any** of the **first four** questions:

- Explain how you will ensure that the interests and wishes of participants are understood and taken in to account.
- Explain how in the case of children the wishes of their parents or guardians are understood and taken into account.

12 Is participation genuinely voluntary?

Questions	Yes	No
Are you proposing to recruit participants who are employees or students of Coventry University or of organisation(s) that are formal collaborators in the project?		√
Are you proposing to recruit participants who are employees recruited through other business, voluntary or public sector organisations?		√
Are you proposing to recruit participants who are pupils or students recruited through educational institutions?		√
Are you proposing to recruit participants who are clients recruited through voluntary or public services?		√
Are you proposing to recruit participants who are living in residential communities or institutions?		√
Are you proposing to recruit participants who are in-patients in a hospital or other medical establishment?		√
Are you proposing to recruit participants who are recruited by virtue of their employment in the police or armed services?		√
Are you proposing to recruit participants who are being detained or sanctioned in the criminal justice system?		√
Are you proposing to recruit participants who may not feel empowered to refuse to participate in the research?		√

If you answered **Yes** to **any** of these questions:

- Explain how your participants will be recruited.
- Explain what steps you will take to ensure that participation in this project is genuinely voluntary.

13 On-line and Internet Research

Questions	Yes	No
Will any part of your project involve collecting data by means of electronic media such as the Internet or e-mail?		√
Is there a significant possibility that the project will encourage children under 18 to access inappropriate websites or correspond with people who pose risk of harm?		√
Is there a significant possibility that the project will cause participants to become distressed or harmed in ways that may not be apparent to the researcher(s)?		√
Will the project incur risks of breaching participant confidentiality and anonymity that arise specifically from the use of electronic media?		√

If you answered **Yes** to **any** of these questions:

- Explain why you propose to use electronic media.
- Explain how you propose to address the risks associated with online/internet research.
- Ensure that your answers to the previous sections address any issues related to online research.

14 Other ethical risks

Question	Yes	No
Are there any other ethical issues or risks of harm raised by your project that have not been covered by previous questions?		√

If you answered **Yes** to **this** question:

- Explain the nature of these ethical issues and risks.
- Explain why you need to incur these ethical issues and risks.
- Explain how you propose to deal with these ethical issues and risks.

15 Research with non-human vertebrates[2]

Questions	Yes	No
Will any part of your project involve the study of animals in their natural habitat?		√
Will your project involve the recording of behaviour of animals in a non-natural setting that is outside the control of the researcher?		√
Will your field work involve any direct intervention other than recording the behaviour of the animals available for observation?		√
Is the species you plan to research endangered, locally rare or part of a sensitive ecosystem protected by legislation?		√
Is there any significant possibility that the welfare of the target species or those sharing the local environment/habitat will be detrimentally affected?		√
Is there any significant possibility that the habitat of the animals will be damaged by the project such that their health and survival will be endangered?		√
Will project work involve intervention work in a non-natural setting in relation to invertebrate species other than *Octopus vulgaris*?		√

If you answered **Yes** to **any** of these questions:

- Explain the reasons for conducting the project in the way you propose and the academic benefits that will flow from it.
- Explain the nature of the risks to the animals and their habitat.
- Explain how you propose to assess, manage and mitigate these risks.

[2] The Animals Scientific Procedures Act (1986) was amended in 1993. As a result the common octopus (*Octopus vulgaris*), as an invertebrate species, is now covered by the act.

16 Principal Investigator Certification

Please ensure that you:

- Tick all the boxes below that are relevant to your project and sign this checklist.
- Students must get their Director of Studies to countersign this declaration.

I believe that this project **does not require research ethics peer review**. I have completed Sections 1-2 and kept a copy for my own records. I realise I may be asked to provide a copy of this checklist at any time.	
I request that this project is **exempt from internal research ethics peer review** because it will be, or has been, reviewed by an external research ethics committee. I have completed Sections 1-4 and have attached/will attach a copy of the favourable ethical review issued by the external research ethics committee. Please give the name of the external research ethics committee here: Send to: Faculty of Engineering & Computing: ethics.ec@coventry.ac.uk Faculty of Business, Environment & Society: ethics.bes@coventry.ac.uk Faculty of Health & Life Sciences: ethics.hls@coventry.ac.uk School of Art & Design: ethics.ad@coventry.ac.uk School of Lifelong Learning: ethics.soll@coventry.ac.uk	
I **request an ethics peer review** and confirm that I have answered all relevant questions in this checklist honestly. Send to: Faculty of Engineering & Computing: ethics.ec@coventry.ac.uk Faculty of Business, Environment & Society: ethics.bes@coventry.ac.uk Faculty of Health & Life Sciences: ethics.hls@coventry.ac.uk School of Art & Design: ethics.ad@coventry.ac.uk School of Lifelong Learning: ethics.soll@coventry.ac.uk	√
I confirm that I will carry out the project in the ways described in this checklist. I will immediately suspend research and request new ethical approval if the project subsequently changes the information I have given in this checklist.	√
I confirm that I, and all members of my research team (if any), have read and agreed to abide by the Code of Research Ethics issued by the relevant national learned society.	√
I confirm that I, and all members of my research team (if any), have read and agreed to abide by the University's Research Ethics, Governance and Integrity Framework.	√

Signatures

If you submit this checklist and any attachments by e-mail, you should type your name in the signature space. An email attachment sent from your University inbox will be assumed to have been signed electronically.

Principal Investigator

Signed ....Sharath............ (Principal Investigator or Student)

Date ....09 July 2012........

Students submitting this checklist by email must append to it an email from their Director of Studies confirming that they are prepared to make the declaration above and to countersign this checklist. This email will be taken as an electronic countersignature.

Student's Director of Studies/~~Project~~ Supervisor

Countersigned........AK.. (Director of Studies)

Date ......9-7-2012....................................

I have read this checklist and confirm that it covers all the ethical issues raised by this project fully and frankly. I also confirm that these issues have been discussed with the student and will continue to be reviewed in the course of supervision.

Note: This checklist is based on an ethics approval form produce by Research Office of the College of Business, Law and Social Sciences at Nottingham Trent University. Copyright is acknowledged.